Geological Disposal

Generic disposal facility designs

December 2010
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1. Appendix C, page 120. To make consistent with the volumetric data presented in Appendix D, replace the 5,225,000m³ value shown in the first column for the Baseline Inventory excavated material volume in higher strength rock with 7,450,000m³.

2. Appendix C, page 120. To make consistent with the volumetric data presented in Appendix D, replace the 6,045,000m³ value shown in the second column for the Baseline Inventory excavated material volume in lower strength sedimentary rock with 6,050,000m³.

3. Appendix C, page 120. To make consistent with the volumetric data presented in Appendix D, replace the 6,243,000m³ value shown in the third column for the Baseline Inventory excavated material volume in evaporite rock with 6,250,000m³.
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Executive Summary

The Nuclear Decommissioning Authority (NDA) has established the Radioactive Waste Management Directorate (RWMD) to manage the delivery of geological disposal for higher-activity radioactive wastes as required under Government policy published in the Managing Radioactive Waste Safely (MRWS) White Paper. This policy also states that the siting of a geological disposal facility (GDF) will be based on a voluntarism and partnership approach. Our recently published report, ‘Geological Disposal: Steps Towards Implementation’, describes the preparatory work undertaken so far, the planning of the future work programme and the management arrangements to deliver it.

This document has been developed as part of a suite of documents that together form our generic Disposal System Safety Case, and is intended to provide information to a wide range of interested parties of the work we have undertaken on the development of a number of illustrative designs for geological disposal in the UK. It also provides the basis for safety assessments which underpin the Disposal System Safety Case.

The range of geological environments that could be suitable for hosting a GDF for higher-activity radioactive wastes in the UK is wide and diverse. Government policy is that the site selection process for a GDF will be based upon voluntarism and partnership. This means that the geological environments available for the disposal facility will depend on the locations of sites identified by the siting partnerships set up by local communities. The approach that RWMD will take until such time as more specific information becomes available is to define a limited number of generic geological environments, encompassing typical UK geologies, for use in engineering designs. The use of generic geological environments does not imply that any specific sites are being considered. The host rock descriptions correspond to three general rock types that are considered potentially suitable to host a disposal facility for higher-activity wastes, and which occur in the UK. The three host rock types considered are described as:

- **Higher strength rocks** – these would typically compromise crystalline igneous, metamorphic rocks or geologically older sedimentary rocks, where any fluid movement is predominantly through divisions in the rock, often referred to as discontinuities. Granite is a good example of a rock that would fall into this category.

- **Lower strength sedimentary rocks** – these would typically comprise geologically younger sedimentary rocks where any fluid movement is predominantly through the rock mass itself. Many types of clay are good examples of this category of rocks.

- **Evaporites** – these would typically compromise anhydrite (anhydrous calcium sulphate), halite (rock salt) or other evaporates that result from the evaporation of water from water bodies containing dissolved rock salts.

These rock types are equivalent to the traditional classification of host rocks (crystalline, sediments and salt) but the terminology reflects some of the developments in understanding of the key characteristics of host rocks such as water movement in terms of, the post-closure safety case. However strength and water flow are not the only geological factors that need to be considered when developing these illustrative designs and these other factors are discussed in more detail.

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1 Throughout this document, the term ‘UK Government’ includes all relevant departments and devolved administrations, but excludes the Scottish Government. The Scottish Government does not support geological disposal – it advocates interim near-surface, near-site storage and disposal facilities so that the waste is monitorable and retrievable and the need for transporting it over long distances is minimal.
Developing these illustrative designs, in turn, helps to enhance our understanding of how waste disposal could be carried out in different geological environments; how safety can be addressed in all phases of development; how long it might take to develop; and what it is likely to cost. This cost is affected by many factors, but the most significant are the inventory of waste, the timing of waste arisings, the timing and duration of each phase of implementation, the geology at the site of the GDF and the design of the GDF itself. At the current stage of our planning for geological disposal, there are inevitable uncertainties about all of these factors.

The ‘Managing Radioactive Waste Safely’ (MRWS) White Paper sets out what is known as the Baseline Inventory of the higher-activity radioactive waste that is a legacy from nuclear activities that have been undertaken or committed to up to now. This includes radioactive materials which have not yet been classified as waste, such as spent nuclear fuel from power stations which has not been reprocessed; plutonium and uranium extracted from spent fuel (SF) that has been reprocessed; and uranium from the nuclear fuel manufacturing process.

The different waste types are classified as: intermediate level waste (ILW), low level waste not suitable for surface disposal (LLW), high-level waste (HLW), SF, uranium (both highly enriched (HEU) and depleted, natural and low-enriched uranium (DNLEU)), and plutonium. A programme to build new nuclear power stations would produce more waste for disposal. The Government believes it is technically possible and desirable to dispose of both new and legacy wastes in the same geological disposal facilities; consequently, we have considered an ‘Upper Inventory’ scenario to consider its impact on the design and layout of the facility.

A range of generic geological disposal concepts are available that can provide safe and secure geological disposal of higher-activity wastes for each of the potentially suitable UK geological settings identified above. Typically, different disposal concepts need to be considered in relation to different geological settings. However, each concept will utilise a ‘multi-barrier’ approach. This approach involves engineered and natural barriers working together to prevent radioactivity being released to the surface in amounts that could cause harm to life and the environment. These barriers include: the wasteform and waste packaging, buffers or backfill surrounding the wastes, mass backfilling, sealing systems, and the surrounding geology.

The illustrative designs describe the processes of waste emplacement and the design characteristics that a disposal facility would need to include. The designs recognise different packaging and disposal processes for different types of waste with ILW, LLW and DNLEU disposed in an ILW/LLW disposal area. HLW, SF, plutonium and HEU would be disposed of in the HLW/SF disposal area. This process is called co-disposal. The disposal operations would share surface facilities, access tunnels, infrastructure and services.

The illustrative designs and layouts have been based on assumed parameters and typical host rock properties; the site specific designs would depend on the geological characteristics of the chosen site such as the local stress field and the distribution and properties of fault zones.

The surface facility design is generic at this stage and does not address aspects of spatial and topographical detail which would only be possible after an identification of a specific site, or sites. Surface facilities allow for the receipt and transfer of waste and its transfer underground via either an inclined tunnel (drift) or shaft. The surface facilities also include all the necessary infrastructure for the support of ongoing construction and the provision of essential services (power, water and ventilation). The illustrative design assumes that the surface site is located directly above the underground disposal area, but recognises that these could be spatially separated and linked by inclined tunnels or drifts.

The illustrative design we have developed for a higher strength and lower strength rock assumes a drift and three vertical shafts to provide security of access and egress, separation of construction and operational activities and separate ventilation circuits for
both construction and operation. Recognising the challenges of maintaining long-term stability of an access drift through overlying sediments and evaporite rocks, we have currently assumed access by shaft only in the evaporite rock illustrative design.

It is assumed that the ILW/LLW disposal area and the HLW/SF disposal area would be horizontally separated to ensure any interactions between the two areas do not compromise the key safety functions of the different engineered barrier components, taking account of the potential thermal, mechanical, hydrogeological and chemical interactions.

The underground layouts are idealised, in that vaults and disposal tunnels are constructed with uniform dimensions on a regular grid pattern. To provide some flexibility, they have been arranged in groups/modules (panels) which would be constructed in ‘blocks’ of suitable geology. In practice, at a specific site, vaults and disposal tunnels would be located and sized based on the site-specific hydrogeological and geotechnical conditions.

Some ILW packages require shielding, and would be transported underground to an operational inlet cell, where they would be removed from a reusable shielded transport container and transferred by remote handling to disposal vaults, for emplacement via a remotely operated overhead crane or remote stacker truck.

Some ILW in self-shielded packages would not require remote handling, and would be transferred using a free steered stacker truck.

HLW and SF would be transported underground in a purpose-designed shielded transport container. The disposal canisters would then be removed from the transport container and then emplaced within the disposal tunnel. Different disposal concepts for SF and HLW have been developed for the rock types considered in this report. These include:

- in higher strength rock in vertical boreholes within a horizontal tunnel surrounded by pre-compacted bentonite blocks.
- in lower strength rock in horizontal tunnels surrounded by emplaced granular bentonite.
- in a salt environment in horizontal tunnels surrounded by crushed salt.

In the MRWS White Paper, the UK Government considers the issue of retrievability of waste in a GDF. It notes that decisions about whether or not to keep a facility (or vaults within it) open once operations cease can be made at a later date, in discussion with the regulators and local communities, and that in the meantime the planning, design and construction of a facility can be carried out in such a way that the option of retrievability is not excluded.

The process of developing and operating the facility will take many decades. An assessment of the potential impacts of carrying out closure operations will be undertaken to optimise the process, taking account of the outcomes of discussions with the regulators and the local community. The decision on when to close the facility after all of the waste has been placed underground for final disposal will take into consideration the views of the local community. The exact condition of the surface site at the end of closure operations will be agreed through consultation with the UK Government, regulators and the local community. When a decision has been taken to close the facility, a programme of backfilling of disposal vaults and tunnels, underground galleries and access ways would be required. This would include a programme of backfilling, the construction of a series of seals with the final backfilling and sealing of the shaft and drift accesses. This would also include a programme of decommissioning of surface facilities.
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E/DRG/0041002 Derived Inventory Reference Case – Underground Layout
E/DRG/0041005 Derived Inventory Reference Case – UILW Underground Emplacement Support Facilities – Longitudinal Section
E/DRG/0041006 Derived Inventory Reference Case – UILW Vault Transfer and Emplacement – Longitudinal Section
E/DRG/0041007 Derived Inventory Reference Case – UILW & SILW/LLW Vault Cross sections
E/DRG/0041008 Derived Inventory Reference Case – SILW/LLW Vault Transfer and Emplacement – Longitudinal Section
E/DRG/0041011 Derived Inventory Upper Inventory – Underground Layout
E/DRG/0041012 Excavation Profiles
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<td>Derived Inventory Reference Case – Surface Layout</td>
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<td>E/DRG/0041052</td>
<td>Derived Inventory Reference Case – Underground Layout</td>
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<tr>
<td>E/DRG/0041056</td>
<td>Derived Inventory Reference Case – UILW Vault Transfer and Emplacement – Longitudinal Section</td>
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<td>E/DRG/0041057</td>
<td>Derived Inventory Reference Case – UILW &amp; SILW/LLW Vault Cross sections</td>
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<td>E/DRG/0041058</td>
<td>Derived Inventory Reference Case – SILW/LLW Vault Transfer and Emplacement – Longitudinal Section</td>
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<td>E/DRG/0041059</td>
<td>Derived Inventory Reference Case – HLW/SF &amp; Pu/U Disposal Tunnel Reception Area and Emplacement – Longitudinal and Cross sections</td>
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<td>E/DRG/0041060</td>
<td>Derived Inventory Upper Inventory – Underground Layout</td>
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<td>Derived Inventory Reference Case – Underground Layout</td>
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<td>E/DRG/0041106</td>
<td>Derived Inventory Reference Case – UILW Vault Transfer and Emplacement – Longitudinal Section</td>
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<tr>
<td>E/DRG/0041107</td>
<td>Derived Inventory Reference Case – SILW/LLW &amp; UILW Vault Cross sections</td>
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<td>E/DRG/0041108</td>
<td>Derived Inventory Reference Case – SILW/LLW Vault Transfer and Emplacement – Longitudinal Section</td>
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<tr>
<td>E/DRG/0041109</td>
<td>Derived Inventory Reference Case – HLW/SF &amp; Pu/U Disposal Tunnel Reception Area and Emplacement – Longitudinal and Cross-sections</td>
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<tr>
<td>E/DRG/0041112</td>
<td>Derived Inventory Upper Inventory – Underground Layout</td>
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<tr>
<td>E/DRG/0041113</td>
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## List of acronyms and abbreviations

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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>AGR</td>
<td>advanced gas-cooled reactor</td>
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<tr>
<td>BMHP</td>
<td>buffer materials handling plant</td>
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<tr>
<td>CDM</td>
<td>Construction (Design and Management) Regulations</td>
</tr>
<tr>
<td>C&amp;I</td>
<td>control and instrumentation</td>
</tr>
<tr>
<td>DCTC</td>
<td>disposal canister transport container</td>
</tr>
<tr>
<td>DNLEU</td>
<td>depleted, natural and low-enriched uranium</td>
</tr>
<tr>
<td>DNO</td>
<td>distribution network operator</td>
</tr>
<tr>
<td>DSFS</td>
<td>Disposal System Functional Specification</td>
</tr>
<tr>
<td>DSSC</td>
<td>Disposal System Safety Case</td>
</tr>
<tr>
<td>DSS</td>
<td>Disposal System Specification</td>
</tr>
<tr>
<td>DSTS</td>
<td>Disposal System Technical Specification</td>
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<tr>
<td>EBS</td>
<td>engineered barrier system</td>
</tr>
<tr>
<td>EIA</td>
<td>environmental impact assessment</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>EDZ</td>
<td>excavation disturbed zone</td>
</tr>
<tr>
<td>GDF</td>
<td>geological disposal facility</td>
</tr>
<tr>
<td>GRA</td>
<td>Guidance on Requirements for Authorisation</td>
</tr>
<tr>
<td>HEPA</td>
<td>high-efficiency particulate air</td>
</tr>
<tr>
<td>HEU</td>
<td>highly enriched uranium</td>
</tr>
<tr>
<td>HGV</td>
<td>heavy goods vehicle</td>
</tr>
<tr>
<td>HLW</td>
<td>high-level waste</td>
</tr>
<tr>
<td>HSE</td>
<td>Health and Safety Executive</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>ILW</td>
<td>intermediate-level waste</td>
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<tr>
<td>LLW</td>
<td>low-level waste</td>
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<tr>
<td>LoC</td>
<td>Letter of Compliance</td>
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<td>MBGWS</td>
<td>Miscellaneous Beta Gamma Waste Store</td>
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<td>MRWS</td>
<td>Managing Radioactive Waste Safely</td>
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<tr>
<td>NDA</td>
<td>Nuclear Decommissioning Authority</td>
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<tr>
<td>NEA</td>
<td>Nuclear Energy Agency</td>
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<tr>
<td>NRVB</td>
<td>Nirex Reference Vault Backfill</td>
</tr>
<tr>
<td>OCNS</td>
<td>Office for Civil Nuclear Security</td>
</tr>
<tr>
<td>PGRC</td>
<td>Phased Geological Repository Concept</td>
</tr>
<tr>
<td>PFR</td>
<td>prototype fast reactor</td>
</tr>
<tr>
<td>PWR</td>
<td>pressurised water reactor</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
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<tr>
<td>RMU</td>
<td>ring main unit</td>
</tr>
<tr>
<td>RWMD</td>
<td>Radioactive Waste Management Directorate</td>
</tr>
<tr>
<td>SEA</td>
<td>strategic environmental assessment</td>
</tr>
<tr>
<td>SF</td>
<td>spent fuel</td>
</tr>
<tr>
<td>SILW</td>
<td>shielded intermediate-level waste</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
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<tr>
<td>SKB</td>
<td>Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Company</td>
</tr>
<tr>
<td>SWL</td>
<td>safe working load</td>
</tr>
<tr>
<td>SWTC</td>
<td>shielded waste transport container</td>
</tr>
<tr>
<td>TRU</td>
<td>Trans-uranic waste</td>
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<tr>
<td>UILW</td>
<td>unshielded intermediate-level waste</td>
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<td>UK RWI</td>
<td>UK Radioactive Waste Inventory</td>
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<tr>
<td>WAGR</td>
<td>Windscale Advanced Gas Cooled Reactor</td>
</tr>
<tr>
<td>WIPP</td>
<td>Waste Isolation Pilot Plant</td>
</tr>
<tr>
<td>WVP</td>
<td>Waste Vitrification Plant</td>
</tr>
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1 Introduction

1.1 Background

The Nuclear Decommissioning Authority (NDA) has established the Radioactive Waste Management Directorate (RWMD) to manage the delivery of geological disposal for higher-activity radioactive wastes as required under Government policy published in the 'Managing Radioactive Waste Safely' (MRWS) White Paper [1]. This policy also states that the siting of a geological disposal facility (GDF) will be based on a voluntarism and partnership approach. Our recently published report 'Geological Disposal: Steps Towards Implementation' [2] describes the preparatory work undertaken so far, the planning of the future work programme and the management arrangements to deliver it.

A range of generic geological disposal concepts are available that can provide safe and secure geological disposal of higher-activity wastes for suitable UK geological environments; although it will be necessary to consider different disposal concepts for different geological environments. For the engineering designs and the safety assessments that underpin the Disposal System Safety Case (DSSC), a limited number of disposal concepts are being evaluated, and illustrative engineering designs (herein referred to as illustrative designs) have been developed for each of three generic geological environments; higher strength, lower strength sedimentary and evaporite rocks. This does not mean that the illustrative designs developed will necessarily be the concept used in those geological environments – at this stage, no geological disposal concepts have been ruled out.

Until such time as more specific information becomes available, the approach that we will take is to define a limited number of generic geological environments, encompassing typical, potentially suitable UK geologies. This report is intended to provide information on the work we have undertaken as part of these preparatory studies – in particular, that we have developed a number of illustrative designs for geological disposal in the UK. These illustrative designs have been developed drawing on work done both in the UK and in international programmes in a range of geological environments [3,4] and aligned with the requirements specified in the Disposal System Specification (DSS).

At this stage in our programme we are using only broad descriptions to distinguish different geological environments. As information becomes available on potential candidate sites, at the appropriate stages in the site selection process we will take into account more specific information on the geological and hydrogeological characteristics that will be necessary for the design and safety case for a GDF.

Developing illustrative designs allows a representation of typical sizes of excavation, designs of rock support, and designs of disposal vaults or cells in a particular rock. The use of illustrative designs and safety assessments of these designs allows us to challenge and identify potential improvements to these designs and allows us to address appropriate disposal solutions for different waste types.

Developing these illustrative designs, in turn, helps to enhance our understanding of how waste disposal could be carried out in different geological environments; how safety can be addressed in all phases of development; how long it might take to develop; and what it is likely to cost. This cost is affected by many factors, but the most significant are the inventory of waste, the timing of waste arisings, the timing and duration of each phase of implementation, the geology at the site of a GDF and the design of a GDF itself [2]. At the current stage of our planning for geological disposal there are inevitable uncertainties about all of these factors.

This approach also provides us with a basis for developing waste package specifications. We are then able to assess, using the established Letter of Compliance (LoC) disposability
assessment process\(^2\), if waste packaging proposals from waste producers are consistent with the requirements currently foreseen for transport, operational and long-term safety.

1.2 The radioactive waste

The ‘Managing Radioactive Waste Safely’ (MRWS) White Paper [1] sets out the Baseline Inventory of the higher-activity radioactive waste from nuclear activities that have been undertaken or committed to up to now. This includes radioactive materials which have not yet been classified as waste, such as spent fuel (SF) from nuclear power stations which has not been reprocessed; plutonium (Pu) and uranium (U) extracted from SF that has been reprocessed; and uranium from the nuclear fuel manufacturing process.

The different waste types to be included within a GDF are\(^3\):

- intermediate-level waste (ILW)
  - shielded intermediate-level waste (SILW)
  - unshielded intermediate-level waste (UILW)
- low-level waste (LLW) – (not suitable for surface disposal)
- high-level waste (HLW)
- spent fuel (SF)
- uranium (U)
  - highly enriched uranium (HEU)
  - depleted, natural and low-enriched uranium (DNLEU)
- Plutonium (Pu)

1.3 Geological setting

The range of geological environments that could be suitable for hosting a GDF for higher-activity radioactive wastes in the UK is wide and diverse. Government policy is that the site selection process for a GDF will be based upon voluntarism and partnership. This means that the geological environments available for the GDF will depend on the locations of sites identified by the siting partnerships set up by local communities. The approach that RWMD will take until such time as more specific information becomes available is to define a limited number of generic geological environments, encompassing typical UK geologies, for use in illustrative engineering designs. The use of generic geological environments does not imply that any specific sites are being considered. The host rock descriptions correspond to three general rock types that are considered potentially suitable to host a disposal facility for higher-activity wastes, and which occur in the UK. The three host rock types considered therein are described as:

- **Higher strength rocks** – these would typically compromise crystalline igneous, metamorphic rocks or geologically older sedimentary rocks, where any fluid movement is predominantly through divisions in the rock, often referred to as discontinuities. Granite is a good example of a rock that would fall into this category.

\(^2\) The process by which RWMD undertakes assessments of waste-packaging proposals and provides advice to the waste-packaging site on the disposability of the proposed waste package. In cases where the proposal will lead to a waste package compliant with GDF safety and environmental cases, this will be signified by the issue of a LoC.

\(^3\) Throughout this document, the term ‘UK Government’ includes all relevant departments and devolved administrations, but excludes the Scottish Government. The Scottish Government does not support geological disposal – it advocates interim near-surface, near-site storage and disposal facilities so that the waste is monitorable and retrievable and the need for transporting it over long distances is minimal.
• **Lower strength sedimentary rocks** – these would typically comprise geologically younger sedimentary rocks where any fluid movement is predominantly through the rock mass itself. Many types of clay are good examples of this category of rocks.

• **Evaporites** – these would typically compromise anhydrite (anhydrous calcium sulphate), halite (rock salt) or other evaporates that result from the evaporation of water from water bodies containing dissolved rock salts.

These rock types are equivalent to the traditional classification of host rocks (crystalline, sediments and salt) but the terminology reflects some of the developments in understanding of the key characteristics of host rocks such as water movement in terms of, the post-closure safety case. However strength and water flow are not the only geological factors that need to be considered when developing these illustrative designs and these other factors are discussed in more detail below.

In order to identify the characteristics of these three host rock types, past work in the UK and other national programmes has been examined.

**Higher strength rocks**: These have been studied for a long time in the UK – for example in the early HLW programme and, more recently for deep disposal of some types of ILW/LLW. Such rocks are also the focus of very advanced projects in Finland and Sweden at the sites chosen for their GDFs for SF and some longer-lived ILW. It has also in the past been studied by Canada, Switzerland, France, Spain, the USA and is currently used in design work in Japan, Korea, China and elsewhere for a wide range of different types of waste.

**Lower strength sedimentary rock**: These have also been studied in the early UK programme for HLW. Other advanced national programmes with site or region-specific disposal concepts for HLW/SF/long lived ILW in such rocks include the Swiss Opalinus Clay, the French Callovo-Oxfordian Clay and the Belgian Boom Clay. More generic sediment design work is ongoing elsewhere, for example in Japan. Deep disposal of ILW/LLW in sediments has also been extensively studied in Switzerland in the past.

**Evaporite rock**: Detailed studies of such rocks in the UK are limited to some preliminary work on disposal of ILW/LLW in anhydrite. In the USA bedded salt is the host for the Waste Isolation Pilot Plant (WIPP) in New Mexico where military trans-uranic waste (TRU) has been disposed of for more than a decade. Germany is also actively developing a disposal concept for higher activity waste in a salt dome and a similar formation was used in the past for ILW/LLW disposal in the former East Germany. Salt and anhydrite have also been investigated in the past for disposal of a range of wastes in several countries, including the USA (dome salt was the host for the earliest proposed HLW disposal facility in Kansas), Switzerland, Denmark and elsewhere.

More background and references to some of the projects mentioned can be found in the following reports [3, 4].

1.4 **Design relevant characteristics of the host rock**

The classification of host rocks allows us to extract design-relevant characteristics from work done in similar environments in the past. This is easiest for evaporite rocks, where design of an operational repository in bedded salt and decades of work in dome salt (particularly in Germany) are complemented by many years of mining experience in this rock. From an engineering point of view, salt is a very attractive host rock and, for most general design aspects, there is little sensitivity to detailed mineralogy or whether it is found bedded or in a dome. This latter difference would, however, influence underground layout – determining whether an extended planar structure or a more compact multi-level option would be preferable. For more detailed design, particularly associated with construction and closure, there are considerations that would be sensitive to the host rock setting, but these do not need to be addressed at this present generic stage. Construction may have to take account of the possible existence of brine pockets in some cases, but potentially suitable evaporites can all be considered “dry” for engineering purposes.
From an engineering viewpoint, the terms ‘higher strength’ and ‘lower strength’ are broad terms. This is understandable, as mechanical aspects of designs are not influenced by strength alone – but also by the depth and the site-specific stress field. In order to make this distinction generic, an engineer might consider these as being rocks needing little mechanical support and those needing much more, respectively. Indeed, for hard rocks, many early conceptual designs for HLW/SF explicitly exclude tunnel/hole lining systems – which considerably simplifies post-closure safety assessment. Nevertheless, when operational safety is considered, it is likely that some form of lining would need to be considered – which would probably be required in any case for groundwater management purposes in most UK geological environments.

As noted above, the stronger rocks considered in deep geological disposal programmes are generally characterised by main water flow occurring in discontinuities. Although this is not universally the case (e.g. welded tuff in the desert environment at Yucca Mountain), it is a reasonable assumption for the current generic studies. Discontinuities, whether water conductive or not, usually occur on all scales: at the very largest (km or more) influencing the GDF layout and at smaller scales determining construction and operational requirements and the useable fraction of rock in emplacement panels. The distribution and properties of discontinuities is, however, highly site specific and hence, despite their importance for design, they are not explicitly considered at the present generic stage.

The lower strength rocks studied to date have included a wide range of sediments, which have often been sub-classified as “hard” or “soft” depending on their plasticity [5]. Nevertheless, compared to crystalline rocks, they are generally more easily deformed and, in response to faulting, often show self-healing by creep or swelling of clay minerals. Designs have been proposed in which unlined tunnels in stronger sediments are selected for HLW/SF disposal. Again based on operational safety considerations, linings may be needed for practical implementation. In any case, especially for softer sediments, lining requirements are critical and may define the maximum practical depth at which a GDF can be constructed.

Water flow systems in sediments show considerable variations. In some cases (e.g. Opalinus Clay, Boom Clay: marine sediments with little tectonic perturbation advective water flow is negligible and solute transport occurs predominantly by diffusion. It is not completely excluded that water-bearing faults may occur or that discontinuities may introduce structural weaknesses, but assumption of homogeneous properties is reasonable for preliminary design for such rocks. This contrasts with other sedimentary host rocks (e.g. Valanginian Marl, Lower Freshwater Molasse: freshwater or highly tectonised sediments where advective flow may occur in fractures or included permeable zones (“sand channels”). Although potentially equally suitable in terms of post-closure performance, such sediments may introduce additional challenges in terms of construction and layout.

In order to avoid biasing generic studies towards particular classes of site, we have initially excluded explicit representation of features that are characteristics of particular rock formations or geological settings, despite their acknowledged importance to design. As soon as volunteer sites come into consideration, these designs will be tailored to the site-specific geological features.

1.5 Multi-barrier approach to geological disposal

A range of generic geological disposal concepts is available that could provide safe and secure geological disposal of higher-activity wastes for each of the potentially suitable UK geological environments identified above [2]. Typically, different disposal concepts need to
be considered in relation to different geological environments. However, all concepts will utilise a ‘multi-barrier’ approach (Figure 1).

This approach involves engineered and natural barriers working together to prevent radioactivity being released to the surface in amounts that could cause harm to life and the environment. It works as follows:

- **The wasteform**: This is the form into which the waste is conditioned to make it suitable for disposal. This form might be chosen so that it is very resistant to the leaching of radionuclides by groundwater; an example would be converting highly active liquor reprocessing waste into a glass wasteform.

- **The waste container**: The conditioned waste is placed in a container (sometimes called a canister), creating what is referred to as the waste package. In some instances, conditioning and immobilisation of the waste is undertaken inside the waste container itself. In some cases (such as is currently assumed for HLW), a secondary or additional outer container used for the handling, transport, storage or disposal of waste packages is used. This is called an overpack. The container must be chosen so that the waste can be safely transported and handled leading up to its disposal at a GDF. The design and materials of the container are selected to provide reliable physical containment under disposal conditions for extended periods of time. This can be achieved by selecting materials (such as copper) which are highly corrosion-resistant under certain chemical conditions or by using sufficient thickness of a metal (such as carbon steel) so that it will take a long time to fail due to corrosion.

- **The buffer or backfill**: The buffer or backfill in this context refers to material that is placed immediately around emplaced waste packages in a disposal facility. The material and design can be chosen so that the buffer or backfill provides one or more beneficial functions. For example, it can be used to control the chemistry of any groundwater that may eventually contact the wastes so that key radionuclides are poorly soluble in the water, as in the case of cement-based buffers or backfills. The buffer or backfill can also provide physical support and protection to the waste package.

- **Mass backfill**: In addition to buffer or backfill to be placed immediately around the waste packages, other types of ‘mass backfill’ will be required to fill excavated access tunnels, shafts or drifts. Again, the material and design can be chosen so that the backfill provides one or more beneficial functions, for example sufficient mechanical strength to ensure other components of the barrier system are retained.

- **Sealing systems**: Complementing the mass backfill, sealing systems will be required to control the movement of groundwater along previously excavated access tunnels, shafts or drifts and through any part of the rock walls in these excavations that are more permeable to groundwater flow, for example as a result of the underground engineering work. Typically, very low permeability materials are considered when developing designs of sealing systems.

- **Geology**: The geological barrier can provide one or more helpful functions in ensuring the safety of disposal. These include:
  - limiting the flow of groundwater into the waste disposal areas (through low permeability of the rock, low hydraulic gradient), so that there is limited potential for the leaching of radionuclides from the wastes
  - providing a long, slow flow path for groundwater to travel from the emplaced wastes to the surface environment, so that radioactivity will have decayed away sufficiently that it cannot reach the surface in harmful quantities
  - providing rock surfaces that retard radionuclide transport by chemical (sorption) and physical (diffusion into dead-end pores) mechanisms
  - restricting the dead-end fractures or pores where groundwater containing radionuclides will effectively be stagnant
o preventing the direct release to the surface environment of any gas generated from the wastes
o protecting the emplaced wastes from extreme changes that may take place at the Earth’s surface, as a result either of natural causes, as in the example of glaciations, or of human actions.

In the case of the geological barrier, we will only know which safety functions we can rely upon when we have conducted investigations at a candidate site.

Figure 1  Multi-barrier approach – illustration of key components

1.6 Retrievability

The term ‘retrievability’ is used to refer to a number of different approaches to remove radioactive waste from a GDF after it has been emplaced. Section 11 of this report sets out the terminology for ‘retrievability’ described by CoRWM and adopted by RWMD.

In the MRWS White Paper [1], the UK Government considers the issue of retrievability of waste in a GDF. It notes that decisions about whether or not to keep a facility (or vaults within it) open once operations cease can be made at a later date, in discussion with the regulators and local communities, and that in the meantime the planning, design and construction of a facility can be carried out in such a way that the option of retrievability is not excluded.

Retrievability has been considered in several international programmes, and has been the subject of wide discussion within waste management organisations and also with other stakeholders. The major focus for retrievability has been the retention of retrieval as an option. There is wide agreement that while the intent is disposal, retaining the option of retrieval, within a step-wise process, has led to wider acceptance that such a long-term project can progress with effective review and control. However, the option to retrieve should not be an argument for compromising on the ultimate requirement for long-term safety and isolation of the hazard or placing a burden on future generations.

The NDA is currently involved in international initiatives looking at the drivers behind stakeholder preferences for retrievability, building on studies over the last decade, and investigating how stakeholder opinions have evolved. These include participation in workshops on retrievability, organised by the Nuclear Energy Agency (NEA). NEA has produced ‘The NEA Retrievability – Scale’ [6] as a communication tool to help explain how retrievability, passive safety and the need for active control are related.
Taking account of the direction in the White Paper and the Environment Agencies’ ‘Guidance on Requirements for Authorisation’ (GRA), retrievability will be considered as an integral component of design development. How retrievability will be addressed in these illustrative designs is discussed in Section 11 of this report.

1.7 Illustrative geological disposal concept examples

Selecting the most appropriate method for implementing geological disposal will require us to carry out assessments and make decisions at different levels of detail. At the current stage of the programme, our work is focused on analysing and developing potentially suitable geological disposal illustrative designs [2]. To underpin the design process, it is sensible to take advantage of the work carried out in the area of geological disposal over the last three decades, in the UK and abroad.

The illustrative geological disposal concept examples were selected following consideration of the concepts identified in the geological disposal concepts studies for ILW and LLW [3] and for HLW and SF [4]. These concepts will be tailored to the specific boundary conditions of UK geology and waste inventory, but also the special programme constraints resulting from the volunteer siting process. At later stages we will develop design solutions to implement the concept or concepts that are then being considered and tailor them to any volunteer site [2]. However, this does not mean that an illustrative concept developed will necessarily be that used in a geological environment – at this stage, no geological disposal concepts have been ruled out.

The sources of the illustrative concept examples are listed below in Table 2. These concepts are supported by extensively documented research and development (R&D) and have been subject to detailed safety assessment, regulatory scrutiny and international review. The WIPP site is operational as the first purpose-built facility for deep geological disposal of radioactive waste.
Table 1  Sources of illustrative geological disposal concepts for host geological environments and classes of waste

<table>
<thead>
<tr>
<th>Host rock</th>
<th>Illustrative Geological Disposal Concept Examples</th>
<th>ILW/LLW</th>
<th>HLW/SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher strength</td>
<td>UK ILW/LLW Concept</td>
<td>(NDA, UK)</td>
<td>KBS-3V Concept</td>
</tr>
<tr>
<td>rocks</td>
<td>Opalinus Clay Concept</td>
<td>(Nagra, Switzerland)</td>
<td>Opalinus Clay Concept</td>
</tr>
<tr>
<td>Lower strength</td>
<td>WIPP Bedded Salt Concept</td>
<td>(US-DOE, USA)</td>
<td>Gorleben Salt Dome Concept</td>
</tr>
<tr>
<td>sedimentary rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporites</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes
a. Higher strength rocks – the UK ILW/LLW concept and KBS-3V concept for spent fuel were selected due to availability of information on these concepts for the UK context.
b. Lower strength sedimentary rocks – the Opalinus Clay concept for disposal of long-lived ILW, HLW and spent fuel was selected because a recent OECD Nuclear Energy Agency review regarded the Nagra (Switzerland) assessment of the concept as state of the art with respect to the level of knowledge available. However, it should be noted that there is similarly extensive information available for a concept that has been developed for implementation in Caloosahatchee-Oxfordian Clay by Andra (France), and which has also been accorded strong endorsement from international peer review. Although we will use the Opalinus Clay concept as the basis of the illustrative example, we will also draw on information from the Andra programme. In addition, we will draw on information from the Belgian super container concept, based on disposal of HLW and spent fuel in Boom Clay.
c. Evaporites – the concept for the disposal of transuranic wastes (TRU) (long-lived ILW) in a bedded salt host rock at the Waste Isolation Pilot Plant (WIPP) in New Mexico was selected because of the wealth of information available from this United States Environmental Protection Agency (EPA) certified, and operating facility. The concept for disposal of HLW and spent fuel in a salt dome host rock developed by DBE Technology (Germany) was selected due to the level of concept information available.
d. For planning purposes the illustrative concept for depleted, natural and low enriched uranium is assumed to be same as for ILW/LLW and for plutonium and highly enriched uranium is assumed to the same as for HLW/SF.

It should be noted that these individual examples are not considered to be the ‘best’ available or even specially suited to potential UK volunteer sites. Rather they provide a spectrum of options (disposal in tunnels, with or without supporting plinth, in boreholes and in caverns), which covers the range within the catalogue of concepts previously described for ILW/LLW [3] and HLW/SF [4]. This approach does not imply any preference over other national concepts or concept options. Over the long term implementation time of a GDF, it is accepted that the catalogues may not be completely comprehensive and new options may need to be considered as they develop in line with progress in science and technology.

These illustrative designs have been used in the current phase of generic assessments of safety and environmental impacts. They will be refined iteratively as the siting progress advances and used to underpin the cost analysis of the range of potential illustrative designs; support the scoping impacts of a GDF; develop the DSS, engineering design, safety case methodology and assessment of the environmental, social and economic impacts; and support further development of the R&D programme.

1.8  Scope of this report

This report forms part of a hierarchy of documents which comprise the generic DSSC. These documents collectively provide evidence to demonstrate that a GDF will be safe. Figure 2 illustrates the generic DSSC document hierarchy including the full list of status reports and how each status report relates to one or more of the Tier 1 safety case reports.
1.9 Limitations

It is stressed that although illustrative designs have been prepared for each of the three geological environments, this does not mean that any of the illustrative designs developed would necessarily be finally chosen for the selected site, or that any of the designs are favoured more than any other. Until such time as more specific information becomes available, the continuing approach will be to define a limited number of generic geological environments, encompassing typical, potentially suitable UK geologies. This approach has been adopted to provide a manageable number of illustrative designs which can be used in the associated assessments of safety, environmental, social and economic impacts whilst keeping open a broader choice of disposal concept options.
2 Disposal system specification requirements and key assumptions

2.1 Context

RWMD has developed a generic DSS which describes the requirements on the disposal system and provides the starting point for RWMD’s design and assessment work. The DSS comprises two documents:

- the generic Disposal System Functional Specification (DSFS) [8], which describes the high-level requirements on the disposal system and is in a form suitable for a wide range of stakeholders
- the generic Disposal System Technical Specification (DSTS) [9], which describes in more detail the requirements on the disposal systems, together with a justification for each requirement.

The illustrative designs have been developed to address the requirements defined in the DSTS.

These documents currently describe generic requirements, reflecting the fact that a site and a disposal concept have yet to be selected. They will be periodically updated throughout implementation of a GDF, for example to respond to changes in regulations and to respond to learning from undertaking assessments. The DSTS, in particular, will evolve from generic to site-specific requirements as site-specific information becomes available.

2.2 Assumptions on the geological setting

In addition to the background discussed previously in sections 1.3 and 1.4, to be able to develop illustrative designs for a GDF within different host rocks and allow associated safety assessment of these illustrative designs, we have had to make assumptions regarding the disposal horizon depth and characteristics of overlaying strata. It is recognised that these assumptions are at a high level at this generic stage and are likely to change in the future as site-specific information becomes available. Nevertheless, they are required to establish a basis for initiation of the design process.

The depth of the disposal horizons in conjunction with the properties of the geological environment will be important in determining the extent to which the geosphere provides isolation and containment of the radioactivity in the waste, and in determining the constructability, excavation characteristics, support requirements and longevity of any underground structures. Important effects of increasing depth on engineering characteristics include increased in situ stress and temperature [9].

The maximum depth for disposal is likely to be defined by practical and economic considerations. In situ rock stresses increase with depth [10] such that the stability of underground excavations (for a given set of rock mass properties) tends to decrease with increasing depth.

The increasing difficulties of construction tend to impose a practical limit to the depth of disposal of approximately 1000 m below ground surface. However, it may be possible to construct a GDF at a greater depth if necessary.

The nature and quality of the host rock must be taken into account when selecting a site and a disposal concept, and will be a major control on underground layout. Rock quality is essentially a summation of the geotechnical or engineering geological characteristics of the rock mass. It will influence and constrain such factors as the size and spacing of the underground openings, the nature of ground support requirements, operational safety within the openings, and the long-term stability of the openings. The layout will also take into consideration the waste handling and emplacement operations including the potential benefits gained from modular design. Modular design would enable waste handling and
emplacement to begin in some disposal modules when construction of other disposal modules continues.

Factors that are likely to have an influence on disposal module excavation and support design include [9]:

- depth of disposal module excavations;
- in situ stress properties of the host rock;
- long-term creep properties of rocks;
- effects of surface degradation on stability of underground excavations and rock support;
- development of disturbed zones around underground openings that may impact stability or provide flow pathways during the post-closure period;
- requirements for maintenance of rock support systems;
- stability during ground vibration (natural and man-made); and
- composition of the groundwater and water/rock interactions.

For the purpose of developing our illustrative designs, the following depths below ground level have been assumed for the three geological environments considered:

- higher strength rock - 650m
- lower strength sedimentary rock - 500m
- evaporite rock - 650m.

In practice, designs for higher strength rocks, and to a certain extent, evaporites are generally less sensitive to depth over this range. For lower strength rocks, as noted in Section 1.4, depth has considerable influence on the required mechanical support for tunnels and caverns – and may even eliminate some options in terms of implementation practicality. For such rocks, therefore, a shallower reference is chosen to allow a wider spectrum of host rock options to be examined. Nevertheless, there are certainly sediments in the UK where considerable deeper facilities would be feasible. These depths have been chosen, to be consistent with those of the concepts on which they have been based.

For all three geological settings, it is assumed the host rock would be sufficiently extensive vertically and horizontally to accommodate the facility. In terms of design, at the present illustrative level, the setting does not play a major role but, when more detailed analysis of access is carried out, site-specific information will be used to examine the significance of overlying (and potentially underlying) sediments.

**Higher strength rock**

For the higher strength rock example, the host geology is assumed to be a higher strength rock overlain by a permeable sedimentary rock.

**Lower strength sedimentary rock**

For the lower strength sedimentary rock example, the host geology is assumed to be a lower strength sedimentary rock overlain by a permeable sedimentary rock.

**Evaporite rock**

For the evaporite rock example, the host geology is assumed to be a bedded evaporite (halite) rock salt overlain by a sedimentary rock.

### 2.3 Geological disposal concepts

Sections 1.4 and 1.7 have introduced the generic host rocks and the basis for selection of GDF illustrative designs. These are now considered in more detail in view of the
representations of potentially suitable UK geological settings described in the previous section.

Higher strength rock
The key design assumptions that have been used in our disposal facility illustrative design for ILW and LLW in a higher strength rock utilise the work previously undertaken by Nirex. This envisages waste disposal in vaults, the dimensions of which are based on those developed for the UK Phased Geological Repository Concept (PGRC) [11]. Since the PGRC only considered LLW and ILW, it has been necessary to consider other international concept options for disposal of the remaining wastes (HLW, SF, Pu and HEU). A concept based on the Swedish SKB KBS-3V concept for SF [12] has been selected. Such vertical emplacement in short boreholes drilled from underground tunnels is the simplest version of a number of different borehole variants [4] and is supported by a particularly large R&D database.

Lower strength sedimentary rock
The key design assumptions that have been used in our disposal facility illustrative design in a lower strength sedimentary rock are based on those developed for the Nagra Opalinus Clay project [13]. The reason for selecting this particular example is that it explicitly considers co-disposal of ILW, HLW and SF and has been recently subject to extensive review [14], which resulted in formal acceptance by the Swiss regulator that it demonstrated the feasibility of siting a repository for such waste in Switzerland. Design information from the Nagra ILW and HLW/SF concepts has been adapted to derive a GDF illustrative design for the significantly larger inventory and different characteristics of UK wastes.

Evaporite rock
The key design assumptions that have been used in our disposal facility illustrative design in evaporite rocks are based on the design parameters that were developed for the WIPP repository in the USA for TRU waste [15] – the first purpose-built geological repository, which has now operated successfully for over a decade. As this is constructed in bedded salt, design modifications focus on differences between the WIPP and UK waste inventories.

For the other UK waste types, the Gorleben concept for HLW and SF in Germany has been selected as a basis. Although Gorleben is a salt dome site in which the reference concept involved vertical emplacement in 300m deep boreholes, a wide range of alternative designs have been developed based on an extensive geotechnical database e.g. the horizontal POLLUX cask disposal concept for HLW, SF, Pu and U [4]. For our illustrative design in a bedded salt we have therefore modified the German horizontal disposal option to allow for the waste to be emplaced within disposal canisters similar to those developed for the other host rock types. This does not, however, preclude later consideration of cask disposal in salt or, indeed, another host rock.

An additional consideration for salt is groundwater management, particularly in the case where overlying aquifers exist (as assumed in the selected UK setting). For both WIPP and Gorleben, concerns about water inflow are reduced by the decision to restrict all access to vertical shafts. At this stage, we have decided to incorporate this into our illustrative design for evaporite rock. However, it is not precluded that drift access may be incorporated into later designs of appropriate to a specific site.

2.4 The wastes
The MRWS White Paper defines the radioactive wastes to be managed in the long-term through geological disposal as those that:

are not managed under the Scottish Executive’s policy for higher-activity waste 4.

Higher-activity waste comprises principally HLW and ILW and includes also the small fraction of LLW that cannot be managed under the LLW Policy. The MRWS White Paper gives definitions and descriptions of these categories of wastes [1].

In addition to these wastes, there are some radioactive materials that are not currently classified as waste, but may need to be managed through geological disposal if they came to be considered as waste in the future. These include SF discharged from nuclear power reactors that is not currently destined to be reprocessed; plutonium separated from SF that has been reprocessed; and separated uranium that comes mainly from the manufacture of nuclear fuel and from the reprocessing of SF.

The Baseline Inventory of higher-activity wastes for geological disposal comprises the total amounts of the relevant radioactive wastes and other materials that could, possibly come to be regarded as waste in the future. It was developed using information from the 2007 UK Radioactive Waste Inventory (UK RWI) [16] and published in the MRWS White Paper, as shown in Table 2.

Table 2  MRWS White Paper Baseline Inventory

<table>
<thead>
<tr>
<th>Materials</th>
<th>Packaged volume</th>
<th>Radioactivity (at 1 April 2040)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Notes</td>
<td>Cubic Metres</td>
</tr>
<tr>
<td>HLW</td>
<td>1, 2, 3, 5</td>
<td>1,400</td>
</tr>
<tr>
<td>ILW</td>
<td>1, 2, 5</td>
<td>364,000</td>
</tr>
<tr>
<td>LLW (not for LURR)</td>
<td>1, 2, 5</td>
<td>17,000</td>
</tr>
<tr>
<td>Spent nuclear fuel</td>
<td>1, 4, 5</td>
<td>11,200</td>
</tr>
<tr>
<td>Plutonium</td>
<td>1, 4, 5</td>
<td>3,300</td>
</tr>
<tr>
<td>Uranium</td>
<td>1, 4, 5</td>
<td>80,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>476,900</td>
</tr>
</tbody>
</table>

Notes:
1. Quantities of radioactive materials and wastes are consistent with the 2007 UK RWI [1].
2. Packaging assumptions for HLW, ILW and LLW not suitable for disposal at the existing low-level waste repository are taken from the 2007 UK RWI. Note that they may change in the future.
3. The HLW packaged volume may increase when the vitrified HLW has been encapsulated within disposal canisters.
4. Packaging assumptions for plutonium, uranium and spent nuclear fuel are taken from the 2005 CoRWM Baseline Inventory [17]. Note that they may change in the future.
5. Radioactive data for wastes and materials was derived using the 2007 UK RWI. 2040 is the assumed start date for the GDF.
6. It should be noted that at present the Baseline Inventory is based on UK Inventory figures, and, as such, currently contains waste expected to be managed under the Scottish Government’s policy of interim near-surface, near-site storage as announced on 25 June 2007 [18].

4 During 2010 the Scottish Government sought views on its ‘Detailed Statement of Policy for the management of higher activity wastes in Scotland’, which includes near-surface, near-site disposal as well as storage.
UK Government policy is that, pending a decision on whether the radioactive materials included in the Baseline Inventory should be declared as waste or not, their possible inclusion into the design and development of a GDF will be considered. Therefore, for planning purposes the Baseline Inventory has been used as the basis for developing a DSS and, in turn, GDF engineering designs that meet this specification.

The Baseline Inventory does not include radioactive waste arising from proposed new nuclear build in the UK. The volume of such waste produced would depend on factors such as the number, size and type of new reactors, fuel burn up and their operational lifetime. The UK Government considers that it would be technically possible, and desirable, to dispose of any waste arising from new nuclear build in a GDF alongside legacy waste, and has committed to exploring this through the MRWS process.

While the information in the White Paper Baseline Inventory and the 2007 UK RWI [16] contains extensive data, this data requires some modification and enhancement to enable it to be used in the NDA’s generic safety assessments. The information provided in the 2007 UK RWI [16] relates to waste streams, but in order to develop designs and safety cases, data is required at the waste package level.

Derived Inventories have therefore been developed from the 2007 UK RWI [16] to provide a dataset focused on the provision of data for waste packages rather than waste streams. As part of this process, four Derived Inventory reports have been prepared for ILW and LLW [19], HLW and SF [20], plutonium and uranium [21], and new-build reactor wastes [22], to assess the four main waste streams. There are some differences between the packaged volumes and radioactivities reported in the Baseline Inventory and those reported in the Derived Inventory as a result of developments made in compiling the Derived Inventory, in particular in packaging assumptions. These assumptions are discussed in more detail in the DSTS [9].

It can be seen that there is a range of scenarios for the inventory of wastes that may require geological disposal. In order to evaluate the implications of these uncertainties for the geological disposal programme, an ‘Upper Inventory’ has been developed to give an indication of the quantities that might need disposal.

The amounts of higher-activity wastes that new build may produce are, at this stage, unknown. In order to deal with this uncertainty, a contribution of wastes from new build has been included within the Upper Inventory. This is so the implications of wastes from this source on geological disposal can be assessed. In particular, it is desirable to understand the relationship between the nature and quantity of such wastes and the implications for the size and design of a GDF and for the level of safety and environmental protection provided by the facility. These implications for design of a GDF are discussed in more detail in Section 14.

The inventory scenarios considered in this report are the Baseline and Upper Inventories. The MRWS White Paper Baseline Inventory [1] defines SF, plutonium and uranium as radioactive materials that are not currently classified as a waste but that may, if it were decided to at some point that they had no further use, need to be managed through geological disposal. The Baseline Inventory therefore includes SF, plutonium and uranium. The waste volumes for each inventory scenario are taken from [9], and are reproduced in Appendix A.

It is recognised that there is large uncertainly over the wastes that may eventually be consigned to a GDF in the future, however we have sufficient flexibility in our GDF designs to accommodate such changes as the GDF design is developed.

2.5 Waste package assumptions

Recognising that many waste packages have yet to be manufactured and decisions about their ultimate design have not yet been made, it has been necessary to make assumptions regarding the form of conditioning and packaging for the purposes of these illustrative
designs. The type of waste packages assumed to be disposed of in a GDF are described below, but it is recognised in the MRWS White Paper [1] that they may change as container designs and disposal solutions are developed and optimised. The number of waste packages for each Inventory scenario is shown in Appendix B.

**ILW and LLW packages**

These would comprise the range of packages defined for use in the 2007 UK RWI [16]. Unshielded ILW (UILW) packages would comprise 500 litre drums, 3 cubic metre drums, 3 cubic metre boxes and a Miscellaneous Beta Gamma Waste Store (MBGWS) box. Shielded ILW (SILW) packages would comprise 4 metre boxes, 2 metre boxes and Windscale Advanced Gas cooled Reactor (WAGR) boxes. LLW would be packaged as 4 metre boxes.

**HLW and SF waste packages**

HLW and SF would be packaged within robust disposal canisters. For the higher strength rock illustrative design, it is assumed that the disposal canisters would be based on the SKB copper canister with a cast iron insert [23]. The design of the disposal canisters will also be influenced by the thermal output and burn up of the SF at the time of packaging and disposal. For the illustrative designs in a lower strength sedimentary rock and an evaporite rock, it is assumed that the disposal canister would be based on the Nagra steel canister design [13]. Nevertheless, this does not imply commitment either to any design option or even using the same material for both HLW and SF in the same GDF.

**Pu and U waste packages**

DNLEU is assumed to be packaged as ILW in 500 litre drums. However, it could also be packaged otherwise - for example in 3 cubic metre boxes. These packaging assumptions are consistent with the White Paper, but it is recognised in the White Paper that these may change.

It is currently assumed that Pu is converted into titanium-based ceramic pucks, with multiple pucks placed in a stainless steel can. Several cans containing pucks would then be encapsulated in glass in a large canister (similar to a Waste Vitrification Plant (WVP) canister) [21]. Two WVP-style canisters, containing the encapsulated plutonium ceramic puck cans, would then be loaded into a disposal canister. For the higher strength rock illustrative design, it is assumed that the disposal canisters would be based on the SKB copper canister with a cast iron insert [21]. For the illustrative design in a lower strength sedimentary rock and an evaporite rock, it is assumed that the disposal canister would be based on the Nagra steel canister design [13].

The disposal canisters for Pu and HEU would be 3.2m long and use the same materials of construction as those given above for HLW and SF for the respective geological environments considered. These packaging assumptions are consistent with the White Paper, but it is recognised in the White Paper that this may change, as package designs and disposal solutions are developed and optimised.

**Disposal canister design**

At this stage of development of our illustrative designs the disposal canister material thicknesses have been based on the SKB (modified for HLW) and Nagra designs, modified in diameter and length to suit UK wastes. We recognise that the current disposal canisters have not considered the detailed aspects of their manufacture and constructability. These aspects will be taken into account in the future development and optimisation of the canister designs, as part of the overall development and optimisation of a GDF. The current disposal canister dimensions used in our illustrative designs are summarised in Table 3 [9].
Table 3  Summary of disposal canister dimensions [9]

<table>
<thead>
<tr>
<th>Disposal canister</th>
<th>Length (m)</th>
<th>Diameter (m)(^{(5)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitrified HLW</td>
<td>3.2</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Pressurised water reactor (PWR)</td>
<td>4.5</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Advanced gas-cooled reactor (AGR)</td>
<td>2.5</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>New build reactor SF</td>
<td>5.2</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Spent Sellafield miscellaneous fuel</td>
<td>3.2</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Spent prototype fast reactor (PFR) fuel</td>
<td>3.0</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Spent submarine fuel</td>
<td>4.5</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>Plutonium</td>
<td>3.2</td>
<td>0.9 or 1.0</td>
</tr>
<tr>
<td>HEU</td>
<td>3.2</td>
<td>0.9 or 1.0</td>
</tr>
</tbody>
</table>

2.6  GDF design assumptions

In order for us to develop illustrative designs for a GDF within different host rocks and allow safety assessment of these illustrative designs, we have had to make assumptions regarding the design, construction, operation and closure of a GDF.

It is currently assumed that no waste packaging or encapsulation would be undertaken at the disposal facility, and all waste would arrive at the facility pre-packaged in a form suitable for disposal. Surface facilities would be on a single site and designed to accept ILW, LLW, HLW, SF, Pu and U for disposal.

Underground, the disposal facility would be split into two separate disposal areas. The ILW/LLW disposal area for the disposal of LLW, ILW (shielded and unshielded) and DNLEU, and the HLW/SF disposal area for HLW, SF, Pu and HEU. A distance of 500m would separate these two disposal areas, to reduce concerns about their interaction. At this stage, this is an assumption and the characteristics of the host rock will determine the exact separation distance and the length and size of the disposal vaults and tunnels.

The facility would be accessed by three shafts and a drift (inclined tunnel) in the higher strength and lower strength sedimentary rock. In the evaporite illustrative design, the facility would be accessed by four shafts. At this stage, the underground facilities are assumed to be constructed on a single level or horizon.

At this stage, it is assumed that the surface facilities would be located directly above the underground disposal facility although it is recognised that they may be horizontally displaced in certain circumstances.

2.7  Disposal facility construction assumptions

For the purposes of initiating the design process, our illustrative designs currently assume that all vertical access shafts would have a finished diameter of 8m and would be excavated using well established technology such as drill and blast. Permanent shafts...\(^{(5)}\)

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\(^{(5)}\) The diameter of the disposal canister is dependent upon the disposal canister design. In higher strength rock, a 0.9m copper canister design is currently envisaged, and for lower strength sedimentary rocks and evaporite, a 1m diameter steel canister design.
support would be provided by concrete and hydrostatic lining installed where necessary to prevent the ingress of water, and a nominal concrete lining where a hydrostatic lining is not required. These assumptions (and those below for the different host rocks) would need to be tailored to individual site properties and the required waste emplacement throughput rates. Indeed, even at the stage of underground construction, continuous geotechnical mapping and inspection would be undertaken to allow tailoring of design to GDF-scale variations in geological characteristics.

The assumptions vary for different geological environments but the principle differences are identified below.

**Higher strength rock**
The drift (an inclined tunnel) would be constructed at a gradient of 1 in 6 and would be some 4km long (including transition curves at the top and bottom) for the assumed depth of 650m. The drift would be 5.5m in diameter for 1,800m (300m depth of overlying sediments) through the lined section and then ‘D’ shaped (5.5m high by 5m wide) to the facility horizon. Construction of the vaults for ILW and LLW and the disposal tunnels for HLW and SF would take place in parallel with operations. However, at the time of first waste emplacement, there would be one UILW vault constructed and operational, one UILW vault undergoing fit-out and one SILW/LLW vault constructed and operational. The fit-out stage includes the placement of the infrastructure, including package-handling equipment, shielded doors, and power and control and instrumentation (C&I) equipment. Construction of one HLW/SF disposal module comprising 10 disposal tunnels would be completed prior to the arrival of HLW and SF.

**Lower strength sedimentary rock**
The drift would be constructed at a gradient of 1 in 6 and would be some 3.3km long (including transition curves) for the assumed depth of 500m. The drift would be 5.5m in diameter for its full length to the facility horizon, but the top 1,800m (300m depth) is assumed to have a lining.

Construction of the vaults for ILW and LLW and the disposal tunnels for HLW and SF would take place on an as-required basis, with two or three tunnels under construction and fit-out at any one time. Construction and commissioning of some disposal tunnels would be completed prior to the arrival of HLW and SF.

**Evaporite rock**
The waste emplacement shaft would be constructed with a finished diameter of 8m. Where the shaft passes through high-permeability sedimentary cover strata, they would be lined with a hydrostatic concrete lining. The bottom section of the shafts would have a concrete lining to give long-term integrity with minimal maintenance.

Construction of the vaults for ILW and LLW and the disposal tunnels for HLW and SF would take place on an as-required basis, with two or three tunnels under construction and fit-out at any one time. Initial construction of some disposal tunnels would be completed prior to the arrival of HLW and SF.

### 2.8 Disposal facility operation assumptions

At this stage, for the purpose of providing a basis for undertaking safety assessment, and considering the logistics associated with moving wastes to the facility, assumptions have been made regarding the timings and throughput rates. Throughput rates have been based on earlier studies [11, 23] or from information drawn from other national programmes. The operational assumptions are assumed to be consistent across the three illustrative designs, and comprise the following.
ILW and LLW
SILW, UILW and LLW waste disposal is assumed to commence in 2040. The disposal rate would be variable over the operational period, and will reflect dispatch rates from the site licence companies. The inlet cells for UILW would be located underground, and are assumed to have a maximum capacity of 2,500 UILW disposal units per year.

HLW and SF
For purposes of planning, the disposal rate for HLW and SF is assumed to be 200 packages per year, commencing in 2075 and taking approximately 48 years.

Pu and U
For purposes of planning, the disposal for Pu and HEU is assumed to be 200 packages per year, following completion of HLW and SF disposal. The disposal of DNLEU could potentially commence at the same time as UILW, provided this does not exceed the inlet cell capacity.

2.9 Disposal facility backfilling and closure assumptions
Closure of the underground part of the disposal facility involves backfilling and sealing the disposal vaults and tunnels, sealing the underground openings, and backfilling and closing the access ways. For each geological setting the following assumptions have been made.

Higher strength rock
Following emplacement of all waste, the ILW/LLW vaults would be backfilled and sealed. The backfill ratio to conditioned waste volume has been assumed to be 1:1. The backfilling of disposal tunnels for HLW and SF would be carried out when all deposition holes are filled in a particular tunnel. For the purpose of developing the illustrative design, it is currently assumed that the backfilling, sealing and closure of the ILW/LLW vaults, roadway infrastructure and main access ways is assumed to take place over a nominal 10 year period after completion of all emplacement operations.

Lower strength sedimentary rock
The ILW/LLW vaults would be backfilled and sealed once each vault had been filled. The backfill ratio to conditioned waste volume has been assumed to average 1:1. The backfilling of disposal tunnels for HLW and SF would be carried out progressively as disposal canisters are emplaced. For the purpose of developing the illustrative design, it is currently assumed that backfilling, sealing and closure of the main access ways and roadway infrastructure would take place over a nominal 10 year period after completion of all emplacement operations.

Evaporite rock
For the purpose of developing the illustrative design in evaporite rock, it has been assumed that the ILW/LLW disposal vaults would not be backfilled as the strata would be allowed to naturally creep and close the excavations over time. The backfilling of disposal tunnels for HLW and SF would be carried out progressively as disposal canisters are emplaced.

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6 For disposal of UILW, a disposal unit consists of either one 3 cubic metre box, one 3 cubic metre drum or four 500 litre drums contained in a stillage. A stillage is a metal frame designed to hold four litre 500 litre drum waste packages so that they can be handled, stacked and transported as a single disposal unit.

7 Creep: the nature of some evaporites to move over time, which can cause the closure of underground openings.
For the purpose of developing our illustrative design, it is currently assumed that backfilling, sealing and closure of the main access ways and roadway infrastructure would take place over a nominal 10 year period after completion of all emplacement operations.
3 Integrating safety within the design

3.1 Safety strategy

RWMD has defined safety, environmental, security and safeguards principles for the design process [24]. These define the objectives of geological disposal as being to ensure that all disposals of solid radioactive waste are made in a way that protects people and the environment, now and in the future, commands public confidence and is cost-effective. Where direct discharge to the environment is unacceptable, concentrating and containing radioactive waste and isolating it from the environment is the internationally accepted strategy for the long-term safe management of such materials. The development of a GDF will follow internationally accepted practices in the use of multiple barriers to achieve safety.

The requirements for construction, operation and long-term safety, environmental protection and transport safety are discussed in detail in the DSS, comprising the DSFS [8] and the DSTS [9]. These documents currently describe generic requirements, reflecting the fact that a site and a disposal concept have yet to be selected. They will be periodically updated throughout implementation of a GDF, for example to respond to changes in regulations and to respond to learning from undertaking assessments. The DSTS, in particular, will evolve from generic to site-specific requirements as site-specific information becomes available.

Figure 3 gives an overview of the process by which the DSS incorporates external sources of information to guide the design and assessment processes, which in turn iteratively leads to refinements and changes in the DSS. Since this figure represents a high-level illustration of the process, to avoid making the figure over-complicated feedback loops have not been explicitly represented. Nevertheless, this clearly identifies the main constraints on and outputs from the design process. Note that the output in terms of LoC gradually evolves into waste acceptance criteria as a site-specific disposal facility becomes defined.

Figure 3 Iterative disposal system development

The iterative process described above in Figure 3 will continue as development of the design and safety case continues. Regulatory hold points throughout this process will require regulators to assess the safety case and agree or give consent to commence the
next stage (for example, construction, commissioning, operation, decommissioning, closure). Safety Functional Requirements will be used to provide the formal, auditable link between the safety assessment work and the design. Safety requirements are set down in terms of design functionality so that designers have the freedom to provide the most appropriate way to implement the required functions. In the future, this may be integrated with a formal requirements management system that includes also constraints set by the desire to minimise environmental impact, maximise acceptability, reduce costs, etc.

The illustrative designs consider the safety of radioactive waste transport, the safety of the construction and operation of a GDF, and the safety of the disposal facility in the very long term, after it has been sealed and closed. More detail on the safety of a GDF during construction and operation of the facility through to sealing and closure can be found in the generic Operational Safety Case main report [25]. This report has been written to demonstrate the safety of operations at a GDF and to show compliance with relevant regulatory targets and limits.

These illustrative designs for geological disposal provide a number of key safety provisions in the packaging, transportation and handling of radioactive wastes within the disposal facility, and are discussed in the following subsections.

3.2 Assessment of Waste packages

The quality of the waste packages is essential to operational safety of a GDF. At the current time, to ensure compliance with the DSS, generic waste package specifications [26, 27] have been developed to specify the requirements for the waste packages. Assessment of a packaging proposal is undertaken as part of the LoC assessment process against the requirements of these specifications. The issue of a LoC gives the waste producer confidence that the waste package has been assessed by an independent waste management organisation in accordance with procedures that are scrutinised by the regulators, and has been found to be compliant with the concept for geological disposal as presently understood. It does not remove the need for further assessment of the waste package against future waste acceptance criteria, but the provision of a final-stage LoC is an essential component of the package record that will be required at that time. Further information on the LoC disposability assessment process is available [28].

3.3 Transport packages

The transport system for radioactive waste includes all of the processes, equipment and management arrangements required for the movement of waste packages from a waste-producing site to a GDF, including, for example, loading of transport packages onto vehicles, monitoring of transport packages and vehicles, overnight stops and changes in transport mode.

The main legislation dealing specifically with the transport of radioactive waste is the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material, TS-R-1 [29]. These Regulations establish international standards of safety which provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material.

The most hazardous materials, including HLW, SF, and some types of ILW, are planned to be transported in large reusable transport containers made from high-integrity materials that provide containment of radioactive materials and shielding from radiation even under transport accident conditions (severe impact and fire). Less hazardous ILW and LLW are assumed to be packaged in ‘industrial packages’ – typically large steel or concrete boxes which are designed to be both a transport and disposal package.

At this stage we have developed two re-usable transport containers to transport waste to a GDF. A Standard Waste Transport Container (SWTC) which would be used to transport
ILW/LLW and DNLEU and a Disposal Canister Transport Container (DCTC) which would be used for the transport of HLW/SF, Pu and HEU [30].

The safety of the packages is provided by a combination of the design and by the regulatory limitation of the quantity and form of the radioactive material that can be carried in the respective transport containers. Details of these designs and their assessment of safety are provided in [30].

3.4 Dispatch and receipt of transport packages

Under currently established arrangements, prior to any waste packages being dispatched to a GDF, a rigorous system of checking and monitoring of each transport package would be carried out by the consigning organisation (the waste owner or the organisation acting on behalf of the waste owner) [31]. This will ensure, in particular, that the specific identification of individual waste packages in terms of the nature and quantity of waste is confirmed and that the package complies with the waste acceptance criteria that we will establish for receiving waste at a disposal facility.

Following receipt of packages by the disposal facility site, administrative checks of the consignment, physical inspection of the transport package, and radiological measurements of surface dose and contamination would be carried out. This would confirm that no damage had been sustained in transport and act as a cross-check on the inspection carried out at the point of dispatch. Facilities would also be available for handling any packages that do not meet acceptance criteria.

3.5 Handling operations

The illustrative designs make provision for ILW packages that are unshielded to arrive at a GDF in a reusable transport container. It is assumed that these transport containers would not be opened until underground in a shielded inlet cell immediately prior to remote emplacement in the underground disposal vaults. All lift heights would be kept to a minimum so as to limit potential damage to the waste package. The UK has experience of handling ILW from the management of a number of waste stores.

The NDA is currently collaborating with other national programmes on emplacement technologies for HLW and SF. For example, full-scale mock-up trials for the emplacement of HLW and SF packages have been carried out in underground or surface research facilities in countries such as Germany, Sweden, France and Belgium [4]. Applying similar principles to that of UILW, the disposal canister would remain in its transport container until it was underground, and the process of removal and emplacement would be undertaken remotely.

3.6 Surface facilities

For conventional and radiological safety reasons, it is prudent to arrange for construction and waste handling operations to be physically segregated, with separate controlled access to each area. The waste handling and transfer operation would be classified for radiological protection, according to approved codes of practice, based on the potential levels of radiation and contamination in each area.

Surface facilities are to be designed to meet all requirements necessary to satisfy the safety case. The buildings and structures, whose failure could impact on the safe operation of the facility, would be seismically qualified and designed to cope with factors such as abnormal wind loading, flooding, rain, landslips, ice and snow deposits, withstand the effects of lightning and extremes of high and low temperature. The design of the buildings would also include appropriate security features as required.
3.7 Transport underground

The illustrative designs for a higher strength rock and a lower strength sedimentary rock assume that waste packages are transported underground on an inclined drift transport system. This system would be designed to meet the safety standards of the Swiss Federal Office of Transport [32] (which are effectively the world safety standards for rack and pinion operation), and would be similar to those used throughout the world for the safe transport of passengers and freight on steep gradients [33]. This comprises rack and pinion locomotives, which are on a separate rail system to that used for surface rail receipt, to avoid direct connection to the underground access drift. In accordance with standard rack and pinion railway practice, the drift locomotives would always be at the downhill end of the train while in the drift. The locomotives and wagons would be equipped with multiple failsafe braking systems. All drift wagons would be specifically designed for rack and pinion operation. They would be equipped with brakes that engage with the fixed rack, and also with parking brakes for use on the level or on normal-adhesion rail track [33].

The illustrative design in an evaporite rock assumes that the waste packages will be transported underground via a vertical shaft. The operating facility at WIPP transports waste through its shafts, and it is proposed to utilise shaft transport at Gorleben [34]. Shaft transport designs would use conventional mine winding systems, which are designed, constructed and operated to the highest safety standards with significant factors of safety required to be built into the design and many failsafe systems. Vertical shafts and their associated winding apparatus are used extensively and internationally as a means of accessing deep underground mines, and technology continues to develop and evolve in this area.

3.8 Construction and operation activities

It is assumed that the underground operations associated with construction (such as excavating the underground disposal vaults and tunnels) would be kept separate from the operational activities (such as the emplacement of waste) with the use of separate access routes underground, separate ventilation circuits and a series of seals. These aspects are discussed in more detail in [35].

The spacing between the vaults would be arranged to minimise geotechnical interactions between adjacent vaults, and will take into account the need for parallel construction and waste emplacement operations.

Tunnelling and underground excavation can be high-risk activities, and construction must be undertaken with robust safety management arrangements, applying the most appropriate standards (including but not limited to mining, Health and Safety Executive (HSE) and Nuclear Installations Inspectorate Regulations). The Construction (Design and Management) Regulations (CDM) [36] apply to all construction work. The application of CDM would include the consideration of appropriate scheduling and co-ordination to take account of concurrent operations being undertaken in close proximity to the construction activities.

A GDF would be constructed using a combination of techniques such as drilling and blasting methods, tunnel-boring machines, continuous miner and roadheader, depending on the nature of the host rock. Safety during construction would generally be provided by working to a well-defined safety management system, and by establishing a strong safety culture. Where novel technology is used, it will be supported by trials.

3.9 Ventilation and drainage systems

In the illustrative designs both the ventilation and drainage for underground construction and waste emplacement areas are designed as separate systems. The design of both systems would allow progressive development of the disposal facility with concurrent construction and waste emplacement. This would be achieved by the installation of
bulkheads and seals between two separate circuits, which could be moved periodically to switch the services for each newly constructed disposal vault or disposal tunnel to the waste emplacement circuit.

3.10 Power supply

The illustrative designs provide for two independent power supplies to the construction and operational areas, each with the capacity to meet the demands for maintaining the facility should one of the supplies fail. Back-up generation and emergency winding facilities would also be provided. The illustrative designs provide for systems which are sufficiently robust to remain safe in the event of system failures such as provision for the recovery of remote handling equipment.

3.11 Reversibility and ease of Retrieval

In line with the MRWS White Paper [1], it is currently assumed that the underground facilities would be constructed and equipped in such a way that the option of waste retrievability is not excluded. Many site-specific features – either individually or in combination – would influence the relative ease or difficulty of retrievability and the potential means of retrieval would be tailored to the characteristics of the host rock. However, inherent in the illustrative designs would be the ability to reverse the waste emplacement operation to retrieve the waste and return it to the surface should that be required during the operational phase of a GDF, or to recover the wastes by mining or similar intrusive methods following final closure and sealing of a GDF.

3.12 Backfilling and sealing

Backfilling and sealing of disposal areas is required to ensure that the multi-barrier functions as envisaged. The use of a combination of sealing plugs and mass backfill, with different performance requirements, is routinely considered in GDF designs and is therefore judged to represent good practice for the closure of the access tunnels and shafts.

Installation of low-permeability seals would limit the flow of groundwater and gas, and the transport of radionuclides along backfilled access ways (and any associated damaged zones around them) connecting disposal modules to the biosphere. A related function would be to isolate sections of access ways that intersect major fracture zones or any other water-carrying features. A further function would be to divide a GDF into several sections, so that geological containment would be implemented in a stepwise manner.

Installation of mass backfill would limit the presence of underground voids (e.g. access ways) to ensure mechanical stability after closure (especially for less extensive salt or low strength sedimentary formations), act as an additional barrier to radionuclide transport and reduce risks of intrusion.

An assessment of the potential impacts of carrying out closure operations will be undertaken to optimise the process, acknowledging the operational timescales of a GDF and taking account of the outcomes of discussions with the regulators and local community.
4 Environmental and sustainability considerations

4.1 Context
The MRWS White Paper [1] states that environmental considerations will form an important input to the selection of sites suitable for construction and operation of a GDF. The Strategy for Sustainability Appraisal and Environmental Assessment outlines the stages in the MRWS site selection process and where the NDA propose to undertake strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) [37]. We will use the SEA and EIA framework to assess the potential social, economic and environmental impacts of implementing geological disposal. Further information on the approach to the SEA and EIA work is provided in [37].

However, in the generic context in which these illustrative designs are presented, it is not possible to be precise about the exact environmental impacts because this is very much a site-specific issue. These issues are discussed in more detail in the ‘Generic Environmental and Sustainability Report’ [38]. However, it is possible to address these requirements at a generic level in a simple manner for generic designs by including consideration of the following.

4.2 Visual impact
It is assumed that a GDF would be constructed on a greenfield site although it is noted that UK Government policy aims to focus new development towards previously developed sites where appropriate. Some brownfield sites may not be appropriate for a GDF given the likely proximity of such sites to existing communities. Notwithstanding this, it is assumed that at the site assessment stage no potentially suitable brownfield sites would be excluded [38].

The design of the facility would be an interactive process taking into account a landscape and visual impact assessment. The visual appearance and setting of a GDF in the landscape would be influenced by a combination of building design, materials, layout, structure, form and colour, landscape works (both on site and off site) and the local topography. For a rural site, the approach to the design of the buildings and landscaping would be likely to be different from that for a site on the edge of an urban development.

At this stage, it is assumed that the surface facilities would be located directly above the underground disposal facility, but it is recognised that surface facilities could be in a different location to the underground site and linked by access drifts.

4.3 Sustainable building design
Environmental performance would be an important aspect of building design. During the optimisation and detailed design process, consideration would be given to issues such as maximising the energy efficiency of buildings, using building materials with low embodied energy, minimising the use of non-renewable resources, and minimising waste arisings during the buildings’ lifecycle.

4.4 Ground vibration
Noticeable ground vibration may occur if explosives are used for underground excavation. Blast parameters would be designed to achieve minimum disturbance to the excavation disturbed zone (EDZ) using appropriate charge densities and detonator sequencing. Surface ground vibration from underground blasting, at the depths assumed for facility construction, should not be an environmental issue.
4.5 Lighting
Particular care would be taken in the specification and siting of all surface lighting in order to minimise light pollution outside of the site without compromising safety and security. A screening bund around the site might also help to minimise light pollution.

4.6 Noise
Noise control measures would be incorporated at the design stage; however, the majority of surface operations would only be undertaken during the day. Where practicable, plant systems would be selected which generate minimum noise levels. Noisy plant and equipment would be enclosed in buildings, which could, if necessary, be fitted with acoustic panels.

4.7 Traffic
Careful attention to the design of the transport system, selection of the most appropriate transport modes, transport routes and sympathetic infrastructure development would all serve to minimise any potential environmental impact and, at the same time, result in a transport system which can be operated in a safe and efficient manner. The on-site transport operations associated with a GDF include the transportation of radioactive waste, construction materials, excavation spoil and personnel.

4.8 Flora and fauna
The construction and operation of a disposal facility and its associated transport infrastructure has the potential to affect local wildlife – both directly within the footprint of surface works and indirectly through disturbance and possible effects on ecosystem function. Consideration would be given during design development to minimising adverse effects on flora and fauna and maximising opportunities to maintain and improve local biodiversity through appropriate habitat creation and management.

4.9 Air quality
Local air quality may be affected by dust generation and by exhaust emissions from both traffic movements and static plant. Adverse effects would be minimised by ensuring appropriate management systems and controls are implemented during construction and operation.

4.10 Socio-economic effects
Many of the socio-economic effects associated with geological disposal are unlikely to be directly influenced by the design of the facility. However, the design would aim to minimise community perturbation and to maintain access to important community services. A Travel Plan for site staff would be prepared, and would feed into the design of transport infrastructure for the site, and facilities for visitors would be included as part of our stakeholder engagement strategy.

4.11 Drainage and groundwater management
The surface water drainage system would be designed to cater for the likely effects of climate change and in accordance with current good practice, with due consideration for topography and local drainage regime.
Design development would take into account the protection of groundwater resources and the potential effects on any groundwater abstractions. This may, for example, involve appropriate treatment of surface site drainage before discharge to soakaway and minimising the area of impermeable surfacing to allow local groundwater recharge.
4.12 Surface spoil management

The generation of spoil from underground excavations has been identified as a key issue in terms of potential environmental effects. For example, the surface storage of spoil would have an effect on landscape character and visual amenity, the transport of large spoil volumes off-site may result in significant noise and air quality effects and it may significantly increase the carbon footprint of the facility. The design would therefore aim to minimise spoil generation and to maximise its re-use on site in the form of stable landscaped screening bunds. Careful consideration would be given to the disposal route for any surplus spoil taken off site and to any commercial value it may have. Appropriate dust control measures would also be taken during soil stripping excavation and in the movement of rock and soil to construct screening bunds.
5 Overview of illustrative designs

5.1 General description of design

This section provides an initial overview of the operations of a GDF. Detailed descriptions can be found in Sections 7 and 8, and a tabulated summary of the illustrative designs in Appendix C. These illustrative designs describe the process of waste emplacement and the design characteristics that a disposal facility would need to include. The illustrative designs are based on the assumption of a single GDF to accommodate all the wastes and materials in the Baseline Inventory [1]. In such a ‘co-located’ disposal facility it is assumed that there would be two distinct disposal areas, separated by an appropriate distance, one for ILW, LLW and DNLEU (ILW/LLW disposal area) and the other for HLW, SF, plutonium and HEU (HLW/SF disposal area). The disposal operations would share surface facilities, access tunnels, construction support and security provision.

The illustrative designs and layouts have been based on assumed parameters and typical host rock properties; the actual disposal concepts chosen and specific designs would depend on the geological characteristics of the chosen site such as the local stress field and fault zones.

5.2 General description of operations

5.2.1 Surface facilities

Surface facilities are provided for the receipt and transfer of waste and their transfer to underground via either an inclined drift or shaft. They also include all the necessary facilities for the support of ongoing construction and the provision of essential services (power, water and ventilation).

The surface facility design is generic at this stage and does not address aspects of spatial and topographical detail which would only be possible once a specific site, or sites, have been identified. For the purpose of developing illustrative designs, the surface facilities have been configured to a simple flat-lying site (Figure 4).

Figure 4 Illustration of surface facilities
5.2.2 Waste transport and reception

The transport system considers the use of sea, rail or road. The surface facilities would be configured to handle package arrivals by these different modes of transport [9]. Depending on the eventual location of a GDF, it is also recognised that radioactive waste and construction materials may be also transported by sea, as is the case in Sweden, where radioactive material is shipped between nuclear sites [39].

If sea transport is utilised, there would still be a requirement to undertake some degree of rail or road transport from the site of arising to a port and/or from a port to a GDF. In order to allow operational flexibility, including during supply of construction and other materials, it would still be desirable for a GDF to be accessible by both road and rail.

Normally, transport packages would be ready for almost immediate transfer underground, so they would be admitted to a package transfer facility (Figure 5), where they would be lifted off the arrival vehicle, monitored and transported underground.

Figure 5 Surface waste receipt facilities

5.2.3 Underground access

Access to the underground facilities would be via a combination of shafts and inclined drift, depending upon the host geology.

Higher strength rock

This illustrative design for a higher strength rock assumes a drift and three vertical shafts to provide security of access and egress, separation of construction and operational activities, and separate ventilation circuits for both construction and operation:

- Shaft number 1 would be used as the access to underground for construction personnel and materials and act as the construction ventilation intake airway.
- Shaft number 2 would be principally used for bringing excavated rock to the surface.
- Shaft number 3 would be equipped with apparatus that would allow people to travel through this shaft, but it would normally be reserved as the exhaust air shaft from the operational side of a GDF.
- The drift would be used to transport waste into the facility. Operational staff would also access the underground via the drift, and it would also be the air intake to the operational areas of the facility.
Lower strength sedimentary rock

It is assumed that the shaft and drift arrangement for the illustrative design in a lower strength sedimentary rock would be identical to that for the higher strength rock, utilising three shafts and a drift.

Evaporite rock

Due to the issues described in section 2.3, it is also currently assumed that four shafts would be used to provide access and egress, which would allow separate construction and operational circuits. These shafts would have the following dedicated uses:

- Shaft number 1 would be used as the access to underground for construction personnel and materials and act as the construction ventilation intake airway.
- Shaft number 2 would be principally used for bringing excavated rock to the surface.
- Shaft number 3 would be equipped with apparatus that would allow people to travel through this shaft in an emergency, but it would normally be reserved as the exhaust air shaft from the operational side of a GDF.
- Shaft number 4 would be used to transport waste into the facility. Operational staff would also access the underground via this shaft, and it would also be the air intake to the operational areas of the facility.

5.2.4 Underground layout

Underground, it has been assumed that the ILW/LLW and HLW/SF disposal areas would be physically separated (Figure 6). This separation distance has been provided to ensure that potential thermal, mechanical, hydrogeological and chemical interactions do not compromise the key safety functions of the different engineered barrier components. An assumed minimum horizontal separation distance of 500m between the ILW/LLW disposal area and the HLW/SF disposal area has been used. At this stage, this is an assumption and the characteristics of the host rock will determine the exact separation distance and the length and size of the disposal vaults and tunnels.

The underground layouts are idealised, in that vaults and disposal tunnels are constructed with uniform dimensions on a regular grid pattern. To provide some flexibility, they have been arranged in groups/modules (or panels) which could be constructed in ‘blocks’ of suitable geology. In practice, at a specific site, vaults and disposal tunnels would be located and sized based on the actual site-specific hydrogeological and geotechnical characteristics of the host rock.

Figure 6 Illustrative underground layout in a higher strength rock for the Baseline Inventory
5.2.5 Underground disposal operations

UILW would be transported underground to an operational inlet cell. Once inside the shielded inlet cell, the UILW would be removed from its shielded reusable transport container and transferred to the disposal vault, for emplacement via a remotely operated overhead crane, as shown in Figure 7.

Figure 7  A disposal vault for UILW in a higher strength rock

SILW and LLW would be transported underground to a reception area and unloaded by overhead crane into the SILW/LLW temporary storage area, ready for disposal in the vaults. SILW and LLW would be emplaced using a free steered stacker truck, as shown in Figure 8.

Figure 8  A disposal vault for SILW and LLW in an evaporite rock
The HLW and SF would be transported underground in its transport container within a covered wagon. The disposal canisters would then be removed from the transport container in a shielded reception area and then emplaced within the disposal tunnel (Figure 9). The disposal operations for plutonium and HEU would be similar to that for the HLW and SF.

**Figure 9** A disposal tunnel for HLW and SF in lower strength sedimentary rock

### 5.3 Backfilling and sealing

The decision on closure of the facility would be made after all the waste has been emplaced and following consultation with the local community. Closure of the underground part of the disposal facility involves backfilling the disposal vaults and tunnels, sealing the underground openings, and backfilling and closing the access ways.
6  Construction

6.1  Surface construction
Initially, sufficient infrastructure, comprising the basic surface facilities, would be constructed to enable underground excavation to commence. The first buildings would be the shaft winder houses, spoil bunker, spoil removal infrastructure and associated offices, workshops and stores to enable the shafts and drift construction to start. General infrastructure, including the main roads and rail access onto site, rail sidings, security, electricity, water and other services, would be constructed in parallel with underground access. If required at this stage, a visitor’s centre could also be constructed on the surface. An initial screening bund for the siding could also be constructed at this time from the excavated spoil.

Following commencement of underground construction via the shafts and drift, the remaining surface facilities would be constructed, including the ILW/LLW waste receipt and handling facilities and associated infrastructure, including the management centre, workshops and stores and fire and rescue station. It is currently assumed that the HLW and SF waste receipt and handling facilities would be constructed at a later date to allow commissioning prior to waste acceptance at the facility. Provision would be made in the surface design for this facility to be constructed without interfering with ongoing ILW and LLW emplacement activities. No additional rail sidings would be necessary, as the throughputs of HLW and SF would be lower than ILW and LLW.

6.2  Underground construction
For the purposes of developing the illustrative designs, the initial underground construction phase of a GDF is assumed to take approximately 10 years, during which time underground access would be established and the facility would be constructed to the point where it could accept waste. The initial construction would comprise the vertical shafts, drift (if required), underground access roadways, the first UILW inlet cell, disposal support facilities, a number of SILW/LLW and UILW disposal vaults and other necessary support facilities for vault operations. This would allow the commencement of waste disposal, with further construction of the remaining vaults taking place on an as-required basis.

The disposal vaults would be constructed in modules, i.e. banks of vaults. This would offer the advantages of repeatability while also providing a degree of flexibility in positioning and orientation to account for variations in geology and geotechnical qualities. Strict control would be maintained on the levels of excavation damage caused to the surrounding rock by controlling the blast design (where applicable) and management of the excavation operations.

The sequence of UILW vault construction and disposal would mean that there would be at least one constructed but non-operational vault separating these activities. This segregation, by solid pillars of rock, coupled with the design of blast patterns, where required, would be sufficient to ensure that blast vibration would not affect the waste emplacement operations.

The underground infrastructure and support facilities have been designed to allow the disposal of waste to take place at the same time as ongoing construction, by providing segregation between these activities. This would be reinforced by utilising airlocks and seals between areas underground.

After a period of operation, disposing of ILW and LLW, the disposal facility would be further developed to the point where it can accept HLW and SF. The underground areas for HLW and SF disposal would be physically segregated from the ongoing ILW and LLW disposal operations. However, these construction and disposal activities would be supported by the same shafts and drift access provided for ILW and LLW operations. This would allow the
commencement of waste disposal, with further construction of the remaining tunnels taking place on an as-required basis.

The illustrative underground layouts have been configured to limit the amount of construction work required up to first waste emplacement. This approach would allow the disposal facility to be developed using continuously improving systems and equipment.

6.3 Extent of excavation disturbance

The extent of any EDZ around an excavation will depend on a number of factors, including hydrological and mechanical properties of the strata, the state of the in situ stress, the size and geometry of the opening and the excavation method.

Ground movement around an excavation can be controlled by the application of appropriate rock support, excavation dimensions and extraction ratios determined prior to excavation and then refined through ongoing geotechnical mapping and testing.

The development of the EDZ will also be dependent on the timing and rigidity of the support emplacement. The inclusion of early, rigid support (precast concrete or cast in situ linings) will result in a restriction of EDZ development, provided the support remains stable. More-efficient support may be offered by using a less-rigid support (for instance, shotcrete and rock bolts) followed by a supplementary support installed some time later.

In general terms, mechanical excavation methods impart less damage to the surrounding rock than drill and blast. However, acceptable results can be achieved by using optimum blast hole patterns and blast initiation delays (smooth-wall or pre-split blasting methods).

These are site-specific issues, and would be addressed in more detail at a later stage in the design process.

6.4 Excavation profiles

As the MRWS programme advances and site investigation data becomes available, this data would be used to develop geotechnical models, which in turn provide the basis for constructing the actual GDF design or designs. The geotechnical models would be refined in the early stages of construction, making use of monitoring systems to assess the stability of the rock and determine the required mechanical support. It is also recognised that support provisions may also need to vary in response to local variations. With the objective of long-term safety and stability, the design of the rock support would be sufficiently robust and incorporate sufficient redundancy to provide stability and reduce maintenance requirements.

Excavation profiles and dimensions would be determined based on the prevailing geotechnical characteristics of the host rock, and would be sufficient to provide adequate long-term stability for the duration of the construction, operation and closure phases. During the construction phase, a system of monitoring would be established to enable decisions to be made regarding the need for maintenance to the excavations as required. The excavation design would be undertaken in such a manner to ensure, as far as is reasonably practicable, that the excavations require little or no maintenance. Where rock support relies on rock bolts and/or shotcrete, then the materials used for such support would be a fit-for-purpose design. It is recognised that this may necessitate the use of double-corrosion-protected or stainless steel rock bolts and quality control of reinforced shotcrete mixes to ensure the stability of excavations over time.

Access to the facility excavations for inspection and maintenance would be available in all but the remotely operated areas. Maintenance requirements of the support systems will vary with the rock types, but as rock strength reduces and/or depth increases, then more reliance would be placed on the supports.
Higher strength rock
For the purposes of initiating the design process, the illustrative designs currently assume that all vertical access shafts would have a finished diameter of 8m and would be excavated using well established technology such as drill and blast. Permanent shaft support would be provided by concrete and hydrostatic lining installed where necessary to prevent the ingress of water, and a nominal concrete lining where a hydrostatic lining is not required. The drift (an inclined tunnel) would be constructed at a gradient of 1 in 6 and, would be some 4km long (including transition curves at the top and bottom) for the assumed depth of 650m. The drift would be 5.5m in diameter for 1,800m (300m depth of overlying sediments) through the lined section and then ‘D’ shaped (5.5m high by 5m wide) to the facility horizon.

General underground tunnel support would be by rock bolt, mesh and shotcrete, as required. The underground excavations would be of varying cross-sections, and generally be ‘D’ shaped. These excavation cross-sections and profiles are shown in Figure 10 and Drawing E/DRG/0041013.

Figure 10 Excavation profiles for higher strength rock

Lower strength sedimentary rock
For the purposes of initiating the design process, the illustrative designs currently assume that all vertical access shafts would have a finished diameter of 8m and would be excavated using well established technology such as drill and blast. Permanent shaft support would be provided by concrete and hydrostatic lining installed where necessary to prevent the ingress of water, and a nominal concrete lining where a hydrostatic lining is not required. The drift would be constructed at a gradient of 1 in 6 and would be some 3.3km long (including transition curves) for the assumed depth of 500m. The drift would be 5.5m in diameter for its full length to the facility horizon, but the top 1,800m (300m depth) is assumed to have a lining. Tunnel support would be by rock bolt, mesh and shotcrete. The use of concrete segmental linings or in situ concrete linings has not been discounted for use in supporting some of the facilities. The underground excavations would be of varying cross-sections, and a mix of ‘D’ and horseshoe shapes. The proposed excavation profiles, based on the Nagra concept, are shown in Figure 11 and Drawing E/DRG/0041063.
Evaporite rock

The waste emplacement shaft would be constructed with a finished diameter of 8m. Where the shaft passes through high-permeability sedimentary cover strata, they would be lined with a hydrostatic concrete lining. The bottom section of the shafts would have a concrete lining to give long-term integrity with minimal maintenance. Conventionally, excavation in evaporite rocks is carried out by either drill and blast or mechanical, roadheader-type machines. Many mining applications in bedded salt deposits utilise continuous (mechanical) miners, which are well suited to forming wide but relatively low (3–6m high) excavations. This type of equipment is in use to form the waste galleries at the WIPP facility in the USA. Tunnel support would be by rock bolt and mesh, as required. The underground excavations proposed would be of varying cross-sections, and would be rectangular in shape. These excavation profiles are shown in Figure 12 and Drawing E/DRG/0041113.

Evaporite rocks and some sedimentary rocks are prone to significant time-dependent deformation, known as ‘creep’. The creep rates in evaporites would govern the length of time an excavation would remain open for disposal without the need for refurbishment. The rate of closure of the excavations would vary with depth, type of deposit and excavation profile. At shallow depths the closure rates could be extremely low, typically of the order of a few millimetres per year, and in such situations the excavations could remain viable for many years with little or no maintenance. As creep rates increase, then excavations would need to be maintained. Regular maintenance of the tunnels would need to be undertaken. This is normally carried out by scaling of the walls of the excavation and, where appropriate, the re-installation of supports.

While it would be possible to undertake maintenance work in some accessible areas of the facility, remotely operated areas would require remote maintenance, where practicable. For
this illustrative design, disposal vault and tunnel dimensions are considered to be suitable
to allow waste disposal within the life span of the excavations with minimal maintenance.

Monitoring of strata movement and assessment of the prevailing creep rate would be
undertaken once excavations are made at the depth of the disposal facility. This data would
assist in ensuring that appropriately sized vaults and tunnels would be excavated to
provide longevity of excavations with minimum maintenance.

6.5 Groundwater management during construction

As previously noted in section 1.4, the hydrogeological characterisation of the host rocks
from the perspective of post-closure safety is not sufficient for design of underground
facilities and supporting services like drainage and ventilation. Even if the host rocks have
low permeability, for the defined settings access must be constructed through overlying
sediments, which could include highly permeable formations or transmissive features.

Design and operational procedures for construction of both tunnels and shafts would be
based on detailed data provided by exploratory boreholes in order to tailor counter-
measures (grouting, freezing, lining, etc.) to local conditions. This would aim to ensure
safety during construction, minimise risks of any accidental inflow during the long
operational period and reduce any impacts on the local hydrogeochemical environment.

In terms of reducing accidental inflow, it is noted here that the design would also take into
consideration the location of all boreholes drilled for site characterisation. If any of these
could potentially provide short-circuits into workings, they would be plugged and sealed
before construction. For evaporite rock rigorous assurance of negligible inflow is critical as
lower salinity waters can cause rock dissolution leading to potentially major perturbations.
This needs to be considered even during the exploration phase in the case for boreholes
drilled through bedded salt into underlying formations (which could contain artesian
aquifers in some settings).

Higher strength and lower strength sedimentary rocks suitable as host rocks would have
low fluxes of groundwater under natural conditions, but flows into open tunnels at depths of
500m or more could be significant due to the artificially high hydraulic gradient. Design of
engineering countermeasures need to consider maximum inflows that may be encountered
– which are likely to be associated with specific structures (faults, fractures, sand channels,
etc.). Depending on their frequency, either local (e.g. grouting) or general (high
performance liners) solutions would be implemented. Even then some small scale
groundwater penetration into underground openings is inevitable – especially when these
will be open for decades. This would be managed by appropriate ventilation and drainage
infrastructure plus a monitoring programme to detect any deterioration in hydraulic sealing
and allow early remediation.

In some cases, major disturbance zones may need to be traversed, which could have very
high transmissivity. In case this is necessary, appropriate technology for groundwater
control would be applied. An important operational aspect is that work to link all future
emplacement panels would be carried out prior to any waste emplacement, to ensure that
potential flooding risks are identified, when there would be no associated radiological
hazard.

Even in salt it cannot be precluded that brine pockets would be encountered during
excavation or that brine seepages would occur during operation. The potential for these
would be determined during site characterisation and again appropriate ventilation,
drainage or sealing measures implemented.
6.6 Operational programme

The timing of the disposal programme is very important for planning, not only for the RWMD but also for the organisations having responsibility for the wastes held in interim storage and for communities affected by the management arrangements for the wastes. The durations of each of the stages leading up to the start of disposal operations identified in the MRWS White Paper [1] can be estimated using information on the processes that are to be followed, combined with experience of technical aspects such as geological investigations drawn from the previous UK programme and from equivalent programmes in other countries. Waste holders are currently assuming that a GDF would be available to receive ILW and LLW in 2040 and HLW and SF in 2075. It is recognised that the basis for the MRWS site selection process is voluntarism and partnership, and consequently the process is driven in large part by discussions with local communities. Therefore, this date, like all other aspects of the programme, must not be seen as fixed but, rather, as a reasonable basis for planning based on current assumptions.

The timing of the receipt of wastes at the disposal facility is based on information in the plans of the waste holders, for example the lifetime plans of the site licence companies. These site licence companies are responsible for decommissioning and clean-up at sites within the NDA estate where wastes are stored or will be produced in the future. There is considerable scope for refining the plans, and close co-operation with the waste holders is envisaged in this area of planning.

Following on from inactive and active commissioning, it is assumed that there would be a ramp up in capacity in the first few years, from an inlet cell capacity of 1,500 packages and drift capacity of 2,000 cycles in 2040 to an inlet capacity of up to 2,500 packages and drift capacity of up to 3,900 cycles in 2042.

The throughput for ILW and LLW for the Baseline Inventory would average approximately 1,800 packages per year for the first 30 years, dropping to some 1,300 packages per year for the next 20 years. Between 2090 and ~2123, the throughput would further reduce, to an average of some 500 packages per year.

This number of packages can be accommodated within the capacity of both the drift (3,900 per year) and a single inlet cell (2,500 per year). It is recognised that the design of the inlet cell in a lower strength sedimentary rock and evaporite rock, where smaller cross-section tunnels would be used, may affect the capacity. However, for the purposes of these illustrative designs, the assumed maximum throughput would remain at 2,500 UILW packages per year. The capacity, and hence the number of operational inlet cells, in other rock types (lower strength sedimentary and evaporite rock) would need to be assessed for each design.

The disposal rate for HLW and SF is planned at 200 disposal canisters per year. The disposal of HLW and SF, based on the Baseline Inventory, would take some 48 years. Disposal of plutonium and HEU, if declared as waste, would be scheduled after the disposal of HLW and SF, i.e. ~2123, and at an assumed rate of 200 packages per year. DNLEU could potentially arrive at the disposal facility prior to 2123 and could be accommodated without exceeding the current annual throughput assumptions.
7 Surface structures and facilities

For the purpose of developing the illustrative surface facility designs, the following assumptions regarding the facility design and operation have been made. Described in the following subsections are the surface operations and infrastructure currently envisaged for receipt of waste packages at the surface, and for their transfer to the drift (or shaft) for transport underground. At this stage, it is assumed that the surface facilities would be located directly above the underground disposal facility, but it is recognised that surface facilities could be in a different location to the underground site and linked by drifts access. We recognise that the detailed design and configuration of the surface facilities would be developed as the project advances, and at appropriate stages of development would need to include consideration of alternative systems, such that an optimised system can be developed.

It should be emphasised that it is not assumed that the surface site fence encompasses the entire footprint of the underground workings. The land above a GDF will be subject to constraints on allowed activities (both before and after GDF closure), but these would be set and administered by national government and not the site operator.

7.1 Waste transport

The disposal facility surface arrangements would include facilities for the receipt and transfer of waste and for their transfer to underground via either an inclined drift or shaft. A schematic arrangement of surface facilities is shown in Figure 13. It is currently assumed that these facilities cover approximately 1km² however it is assumed that the layout of the surface facilities will be tailored to the site/or sites.

Figure 13 Schematic surface facilities

The rail and road transport systems (outlined below) would be sufficient to enable transport of the packages to the disposal facility in order to meet the anticipated rate of waste arisings and the currently assumed emplacement rate profile of a GDF (Section 6.6). All
transport packages, whether arriving by road or rail, would be transported to the site on appropriately covered vehicles.

The illustrative designs have allowed for ILW and LLW packages to arrive at an average rate of 1,800 a year from 2040 onwards, with 200 HLW, SF, plutonium and HEU disposal canisters per year arriving from 2075 onwards [23].

7.1.1 Rail transport

The transport system considers the use of sea, rail or road. Our surface facilities would be configured to handle package arrivals by these modes [9]. However, the capacity of the rail receipt system has been designed with sufficient redundancy to accommodate all transport packages arriving by rail in consignments, if required.

On-site rail sidings have been provided to enable trains with ILW and LLW to be separated into smaller numbers of wagons which would be marshalled ready for shunting to the ILW/LLW waste package transfer facility for onward transfer to the drift (or shaft in the evaporite design). On-site rail arrival sidings have been provided to enable these operations to be carried out safely and effectively.

For the illustrative designs, the arrival sidings have been designed to meet the following requirements:

- To accommodate a main-line train, currently assumed to consist of up to 12 wagons [30].
- To handle the expected peak daily arrival rate.
- In conjunction with the dispatch sidings, to act as temporary short-term storage so that in the event of unplanned interruption to the disposal operations (assumed to be up to 1 week in duration) all transport packages already in transit could complete their journey to the facility. In that event, further dispatches from waste producers' sites would be delayed until the backlog could be cleared.
- Disposal canister transport containers (DCTCs) would not be stored in the sidings but placed into the HLW, SF, plutonium and HEU waste transfer building temporary storage area.
- In conjunction with the dispatch sidings, the arrival sidings provide sufficient storage for the entire facility fleet of rail wagons and sufficient space to marshal these wagons.

These requirements for the arrival sidings would be met by four straight and parallel tracks, each 240m long, giving a capacity of 48 wagons [16].

For the illustrative designs, the dispatch sidings have been designed to:

- permit the shunting of wagons carrying empty reusable transport containers (ILW), into trains of up to 12 wagons in length, prior to delivery to the main-line sidings for collection by a main-line locomotive
- handle the expected peak daily dispatch rate
- in conjunction with the arrival sidings, provide the storage capacity stated above.

These requirements for the dispatch sidings would be met by a further four straight and parallel tracks, each 240m long, giving an overall site capacity of 96 wagons [30].

By making the layout of the arrivals and dispatch sidings the same and by grouping them together on the site, a degree of operational flexibility would be provided.

7.1.2 Road transport

The current planning assumption for our illustrative designs is based an average rate of approximately two vehicle arrivals per day [30].

Facilities would be provided at the site entrance to permit up to two heavy goods vehicles (HGVs) to park at any time while documentation is being checked at the gatehouse. In
addition, a turning area would be provided outside the site security fence to turn back all unauthorised vehicles.

Within the site, a parking area would be provided for up to 26 HGVs, to accommodate both arrivals and despatches and also to provide parking for HGVs and trailers not in use. A segregated parking area would be provided for HGVs carrying transport packages, while waiting to enter the waste package transfer facility. Finally, there would be a separate bay for HGVs whose transport packages had been accepted on site but are awaiting transfer to the transport container and maintenance facility.

HGVs departing to a waste producer's site would, if possible, be loaded with an empty reusable transport container at the waste package transfer facility, depending on the scheduled requirements of the waste producer. No special facilities would be provided, other than an area for departing vehicles to wait while dispatch documentation is being checked at the transport management centre.

7.1.3 Sea transport

Depending upon the location of the disposal facility, there may be an opportunity to transport materials or waste packages by sea, as is the case in Sweden, where a radioactive materials transport ship is used for both fuel and waste shipments between nuclear sites.

In considering the most suitable ship type, regard must be taken of the following:

- regulations concerning the safe handling, stowage and carriage of radioactive waste by sea as well as crew safety
- restrictions at dispatch and receipt ports in respect of ship length, breadth and draft and shore-side facilities
- the cargo-handling operation that is best suited to the cargo and the port infrastructure.

If sea transport is utilised, there may be a requirement to undertake some degree of rail or road transport (from the site of arising to a port and or from a port to a GDF) unless the surface facilities were located directly on the coast with their own harbour. In order to allow operational flexibility, including during supply of construction and other materials, it would still be desirable for a GDF to be accessible by both road and rail.

7.2 Waste receipt and transfer

7.2.1 Transport package receipt and transfer facilities

The process would begin with the road or rail transportation of the waste packages from the waste-packaging and interim storage sites to the disposal site. A rigorous system of checking, monitoring and verifying the performance and contents of each package would be carried out by the consignor before leaving the waste producer's site.

Upon arrival of HGVs or trains carrying transport packages, the consignment documentation would first be checked and processed at the gatehouse and transport management centre before the packages are allowed on site. Vehicles would then progress to their respective temporary holding areas (either an HGV park or rail sidings) before being moved to their destination, the waste package transfer facility.

In order to eliminate the risks associated with unauthorised trains inadvertently entering the designated nuclear-licensed site boundary area, it is currently proposed that two off-site rail sidings parallel to the main line be provided to receive the consignments of rail wagons carrying transport packages. The sidings would be unmanned but would include a communications point to enable documentation to be confirmed with the transport management centre.

Wagons would be collected and brought to site by a dedicated shunting engine. To reduce the potential consequences of an impact incident, its speed would be restricted. Empty
wagons carrying reusable transport containers would be placed here by the shunting engine for return to the main-line sidings. In the event of a breakdown affecting the disposal facility operations, the receipt and dispatch sidings would have the capacity to hold a 1 week supply of rail wagons. If packages could not be placed underground for some extended period, then consideration would be given to returning the packages to the consignors and stopping further deliveries.

The primary facilities for transferring transport packages from road or rail arrivals to the underground transport system would be grouped together in a central complex (Figure 14). The ILW/LLW receipt and dispatch facilities would be capable of handling transport packages arriving by any combination of rail and road. The HLW/SF receipt and dispatch facilities are currently designed for handling transport packages arriving by rail only. It is currently assumed that these facilities would be modified (as necessary) at a later date to accommodate arrivals of DNLEU in the ILW/LLW facility and plutonium and HEU in the HLW/SF facility.

Figure 14  ILW/LLW receipt, transfer and dispatch facilities

The ILW/LLW package transfer facility would allow the unloading of rail and road vehicles. Road vehicles would reverse into one of two bays, where the tractor unit would be driven away and the trailer covers removed, allowing radiation monitoring and visual inspection of the transport package prior to the transfer operation. If necessary, manual decontamination of the transport package and or road vehicle would be undertaken. Once accepted, the transport package would be released from the trailer and transferred within the same building to a transfer wagon using an overhead travelling crane (safe working load (SWL) 80t). Where practical, throughout the facility, lift heights would be minimised and package movement rates controlled. The layout of this and other facilities would seek to restrict the ability to lift transport packages over one another, to avoid the possibility of collisions and one or more packages damaged due to dropped loads.

As well as having fail-to-safe systems, the crane would incorporate a retrieval system, so that in the event of a total electrical failure it could be mechanically operated to safely lower transport packages to floor level.

ILW and LLW transport packages arriving by rail would be handled in a similar way. The main-line rail wagon would be shunted into one of two bays, where the cover would be removed to permit monitoring and inspection. There would be provision for manual decontamination of the transport package and or rail wagon if necessary. Normal
procedures would then be a direct transfer by overhead travelling crane from the main-line wagon to the drift locomotive.

In the unlikely event of damage to an ILW transport package or any other non-conformance, it may be undesirable to return the package to the consignor. Therefore, there would be a facility to transfer non-conforming transport packages to one of two shielded temporary storage cells within the building, until either the anomalies could be resolved or the package could be transferred to the transport container maintenance facility for further rectification work. Very simple repairs could be undertaken in the temporary set-down area.

HLW and SF transport packages arriving by rail would be handled in a similar way to the ILW and LLW packages but in a separate adjacent facility (Figure 15). Main-line rail wagons would be shunted into one of three bays, each of which would accommodate two rail wagons. Based on an arrival rate of 200 packages per year, this would therefore allow 1 week’s worth of deliveries to be temporarily stored within the facility. The covers would be removed to permit monitoring and inspection. There would be provision for manual decontamination of the transport package and/or rail wagon if necessary. Normal procedures would then be a direct transfer by overhead travelling crane from the main-line wagon to the drift locomotive (or shaft transfer system in the evaporite rock illustrative design).

In the unlikely event of damage to an HLW and SF transport package or any other non-conformance, it may be judged undesirable (and potentially not possible) to return the package to the consignor. Therefore, there would be a facility to transfer non-conforming transport packages to one of the temporary storage cells within the building, until either the anomalies could be resolved or the package could be rectified to allow transport underground.

Empty reusable transport containers would be returned to the surface and into the relevant transfer facility for routine contamination monitoring prior to dispatch. Six testing stations would be provided in the ILW/LLW transfer facility, and a single test station would be provided in the HLW/SF transfer facility. These would be provided with facilities to allow rectification of containers failing the tests.

Following clearance for re-use, empty ILW transport containers would normally be stored either in the small temporary storage area adjacent to the testing stations or they would be transferred to the main covered store for transport containers, adjacent to the transport container maintenance facility. Temporary storage would also be provided for transport stillages awaiting re-use, and also for new disposal stillages, which would be taken underground.

DCTCs cleared for re-use would normally be stored in the transfer facility, in a temporary storage area adjacent to the test facility.

Empty road or rail vehicles would normally remain in the reception bay of the relevant package transfer plant, awaiting transfer of an empty reusable transport container, by the
overhead travelling crane, from the temporary storage area to the vehicle. The vehicle would then depart as already described.

7.2.2 ILW transport container maintenance and storage facilities

It is currently assumed that there would be separate maintenance and storage facilities for the ILW/LLW and HLW/SF (including plutonium and HEU) transport containers. However, in future designs, depending upon the location of the site, these facilities could be housed in the same building.

When an ILW transport container (shielded waste transport container – SWTC) requires more extensive maintenance than minor turn-round inspection, a self-propelled bogie would transfer it from the transport package transfer facility to the transport container maintenance and storage facility. The maintenance and storage facility would provide for:

- repair of containers that had failed the turn-round inspection in the transport package transfer facility
- scheduled annual inspection and maintenance of all containers
- scheduled periodic inspection and maintenance of all containers (more extensive than annual maintenance)
- decontamination and inspection of transport stillages
- recovery and rectification of non-conforming transport containers and/or waste packages, as described earlier.

Every transport container entering the maintenance facility would pass through an inspection and monitoring area and then into an interlocked containment booth for opening and, if necessary, decontamination.

The containment booth would contain a shielded and filtered cell with purpose-designed remote handling equipment for opening transport containers and removing any waste package(s), even under difficult circumstances involving damaged or other non-compliant items. The remainder of the containment booth would be unshielded, but equipped for decontamination operations, and would be large enough to accommodate a transport container, its lid and a transport stillage in separate lay-down areas.

Even for routine scheduled maintenance, the following operations would be carried out remotely until it had been confirmed that the container is empty and has no major internal contamination:

- lid removal
- transfer of the lid, container body and any transport stillage from the shielded cell to other parts of the containment booth for decontamination
- any decontamination found to be necessary
- transfer of decontaminated items out of the containment booth to other parts of the maintenance facility for further treatment.

The maintenance facility would provide the capability for all scheduled maintenance and mechanical repair of the transport container. Separate areas would be provided for machining and welding activities. Other areas would include the lifting equipment store, the pressure testing station, the leak testing station and facilities for checking the dimensional tolerances of repaired containers.

In addition, this facility would be able to receive any transport packages that might fail acceptance tests, and would have the equipment to take the necessary remedial actions. The main covered storage area for reusable transport containers would be adjacent to the maintenance facility.
7.2.3 **HLW and SF transport container maintenance facilities**

When a DCTC requires more extensive maintenance than minor turn-round inspection, then the transport container would be delivered to the HLW/SF transport container maintenance area. This would be a segregated area within the HLW/SF waste package transfer facility, but would only accept empty transport containers.

The maintenance facility would provide for:

- repair of containers that had failed the turn-round inspection in the HLW/SF transport package transfer facility
- scheduled annual inspection and maintenance of all transport containers
- scheduled periodic inspection and maintenance of all transport containers (more extensive than annual maintenance).

Every transport container entering the maintenance facility would pass through an inspection and monitoring area and then into an interlocked containment booth for opening and any necessary decontamination.

The containment booth would be equipped for decontamination operations and would be large enough to accommodate a transport container and its lid in separate lay-down areas.

The maintenance facility would provide the capability for all scheduled maintenance and mechanical repair of the transport container. Separate areas would be provided for machining and welding activities. Other areas would include the lifting equipment store, the pressure testing station, the leak testing station and the metrology room (for checking the dimensional tolerances of transport containers).

7.3 **Construction support facilities**

To enable the ongoing underground construction, there would be a number of surface facilities to support these activities. The primary buildings are described below, however it is acknowledged that is not an exhaustive list of buildings and there would be a requirement for a number of other additional buildings such as a geotechnical laboratory and core store. The primary buildings would include:

7.3.1 **Rock-crushing facility**

The rock-crushing facility would be divided into two sections: an excavated rock store that would contain a supply of suitable rock ready for crushing that has previously been removed from the disposal facility, and the crushing plant. Rock from the surface stockpiles would then be moved to the rock store in the rock-crushing facility. A mechanical front-end loader would place this rock in a hopper that feeds the rock-crushing facility. Multiple crushing processes would be required to get the required size fractions. The crushed rock would then be fed by either belt or screw conveyor to the silo tanks in the buffer materials handling plant, to be incorporated as backfill directly (rock salt) or mixed with bentonite (for the higher strength rock illustrative design).

Surplus rock spoil, not able to be accommodated within the surface screening bunds, would be taken off site via a conveyor from the rock-crushing facility through to the rail system.

7.3.2 **Surface stockpile for excavated rock**

With the exception of the illustrative design in an evaporite rock, it is assumed that at least some of the rock excavated from the underground workings would be retained on site by the creation of a screening bund around the site of the works, although this would depend upon the nature of the host rock. The bund would be progressively constructed and landscaped throughout the lifetime of a GDF. A screening bund might be formed between the perimeter fence and the rail receipt sidings at an early stage of construction and before commencement of disposal operations. This would provide isolation and visual screening.
from members of the public from transport packages in the rail sidings during GDF operations.

Although rock excavated from the underground development of roadways, vaults, disposal tunnels, etc., could be brought up shaft number 1 at any time, it is assumed that the surface operation to place the rock in the perimeter screening bund would be constrained to daytime hours by planning conditions. Therefore, in order to allow rock to be removed from underground as expeditiously as possible, a stockpile would be required at the surface. The stockpile would have a capacity of approximately 3,500 m$^3$ in total, and would be enclosed in a building in order to control noise and also the spread of dust. The rock would be taken by an enclosed belt conveyor from shaft number 1 to the top of the covered building and discharged on to either of two stockpiles. During daytime working hours, the material would then be loaded by a front-loading shovel into an articulated dump truck for use in the construction of the screening bund around the site.

If it is not possible to store all of the excavated rock on site, arrangements would be put in place to transport surplus excavated rock off site. These arrangements would consist of a conveyor to transport the spoil from the rock-crushing facility to the rail sidings, to be taken off-site.

Due to the nature of the excavated material, in the evaporate rock illustrative design, it is planned to dispose of the excavated rock salt off site via the rail system. Material may therefore have to be imported to a GDF site to allow construction of these bunds. Depending upon the location of the site, some of this material could be provided during initial surface site construction works.

### 7.3.3 Buffer materials handling plant

A buffer materials handling plant (BMHP) is only foreseen for the higher strength rock and lower strength sedimentary rock illustrative designs (the rock crushing plant serves this purpose for salt).

In the higher strength rock illustrative design, buffer material would be formed into pre-compacted blocks and rings, sealed in a plastic liner and transferred to the drift for onward movement underground. To produce the pre-compacted blocks, bentonite would be withdrawn from storage bins and transferred, blended and weighed, and the moisture content of the mix would be adjusted to the required level. The bentonite would then be transferred to one of a number of block compaction machines. Completed blocks would then be conveyed from the compaction machine to the block-loading bay, where blocks would be inspected, sorted and placed on suitable rail cars. Blocks would be grouped logically on cars to provide the desired combination for the deposition hole being filled. These blocks and rings would be placed within the deposition hole surrounding the disposal canister.

The BMHP would also be required to produce crushed rock spoil and bentonite, to be used as mass backfill in the disposal tunnels and roadway infrastructure.

In the illustrative design for a lower strength sedimentary rock, the BMHP would be required to produce blocks of bentonite and granulate.

### 7.3.4 Construction offices

The office block would provide facilities, including construction personnel changing facilities, a control room linked to the main GDF control room, a lamp room and a medical room.

### 7.3.5 Construction workshops, stores and marshalling area

Workshops and stores would be provided to service the shafts site. The workshops would be equipped with both mechanical and electrical plant servicing areas and would have an overhead travelling crane. The stores would have a mobile racking system for smaller parts and an open area with an overhead travelling crane for the larger items of stored
equipment. These would be located adjacent to a marshalling area for the storage of construction materials.

7.3.6 Fire and rescue station

A fire and rescue station would be provided on the surface site. This would serve both the surface and underground in the event of an emergency. The station would be a combination of a conventional fire station and a mines rescue station, and would be staffed by trained fire and rescue personnel, to provide a permanently available service.

Facilities would include fire engine(s), self-contained breathing apparatus, protective clothing (e.g. fire suits and full body suits), a lamp room, active change rooms and showers, whole-body radiological monitoring, an ambulance and a first aid room.

7.3.7 Explosives store

Subject to the properties of the host rock, it is expected that explosives might need to be used as part of the underground excavation operations. Therefore, an explosives store would be provided on site to ensure that explosives would be held securely and would be available as and when required. The store would be sited on the construction site, and its delivery, storage, transportation and use subject to a strict control based statutory requirements.

7.4 Waste emplacement support facilities

The following principal surface facilities would support the ongoing waste emplacement activities at a GDF.

7.4.1 Active ventilation and effluent treatment plant

An active ventilation plant and liquid effluent treatment facility would be provided to treat all active liquid effluent arising from the surface and underground operations within the main waste emplacement building complex. All discharges would be led to the atmosphere through a stack located at the side of the complex. Equipment would be in place to monitor quantities of dust, aerial contaminants, gases and radionuclides. Systems would also be in place to mitigate these releases, if any were identified.

Any active liquid effluent, collected from underground operations, would be brought up the drift (or waste emplacement shaft in the evaporite rock illustrative design) by tanker and would be shunted into a covered unloading station. A flexible coupling would then be connected to the tanker, and the contents pumped to receipt tanks at the active effluent treatment plant.

7.4.2 Management centre

The management centre and control room would provide the following facilities:

- In conjunction with the transport management centre, round-the-clock operational control and monitoring of all transport package arrivals and dispatches.

- A control room that would be the focal point for monitoring and controlling the disposal facility not only during normal operations, both surface and underground, but also during emergencies (during site emergencies the control room would also function as the emergency control centre). The location of the control room has been chosen so that control room staff would have good direct visibility of the main operations within the rail sidings and the transport package receipt and transfer facilities, as well as the usual alarm and CCTV monitoring, and back-up systems.

- Processing and recording of all quality assurance documentation, including maintenance records.

- Change-room facilities for workers involved in both active and non-active operations on the surface and underground.
• Cafeteria and welfare facilities.
• Health physics monitoring and records service.
• Office accommodation for management, operations and support staff.
• Offices for use by the various inspectorate organisations, including HSE and EURATOM, which would periodically visit the facility.

7.4.3 Transport management centre

The transport management centre would be located close to the road and rail arrivals and dispatch areas. Its primary function would be to check and process documentation relating to arriving transport packages and departing reusable transport containers and transport casks. The primary control would be through inventory tracking procedures. The transport management centre would be closely linked to the main control room, which would have overall responsibility for the co-ordination and control of vehicle movements both on and off site.

7.4.4 Drift transport vehicle maintenance facility

For the higher strength and lower strength sedimentary rock illustrative designs, where waste would be emplaced using a drift transport system, this facility would be the maintenance area for the drift locomotives. A rail track running the full length of the facility would provide parking for up to three drift locomotives or wagons. The facility would have a monitoring and decontamination area, inspection pit, machine and welding shop, and would be served by an overhead travelling crane with a suitable SWL. To allow the drift locomotives and rolling stock to be brought to the site, and removed if more specialised repairs would ever be necessary, they would be designed to operate on conventional rail track as well as the rack and pinion system.

For the evaporite rock illustrative design, where waste would be emplaced using a shaft transport system, the maintenance facility would be integrated into the waste package transfer buildings. It would be accessible by rail track to the emplacement shaft transport system. The facility would have a monitoring and decontamination area, an inspection pit, and a machine and welding shop, and would be served by an overhead travelling crane with a suitable SWL.

7.4.5 Shunting engine and main-line wagon maintenance facility

A separate maintenance facility would be provided, adjacent to the drift wagon and locomotive facility, for the shunting engines and the fleet of main-line rail wagons. The facility would have an inspection pit and a machine and welding shop, and would be served by an overhead travelling crane with a suitable SWL. Some repairs and routine maintenance could be contracted off site.

7.4.6 Laboratories

The laboratories would share the same building as the active laundry (within the active area). Their role would be to analyse active or potentially active liquid and gaseous samples taken from various operational processes on the site. This would also include sampling and analysis of liquid and airborne discharges to ensure that compliance with regulatory limits was maintained. In addition, analysis of environmental samples (e.g. air, water) would be carried out to monitor and record the environmental effects of the disposal facility operation. The laboratories would be equipped with fume hoods and glove boxes. The relatively small liquid effluent arisings would be transported to the active effluent treatment receipt tanks for processing.

7.4.7 Active laundry

It is assumed that an active laundry would be provided on site. This would be a separate facility within the active area to handle the laundering of clothing used in the active area. It
would be similar to any normal industrial laundry, with washers and drying systems, but in addition would have an active change area and radiological controls and monitoring. The laundry would also wash protective clothing and respirators for re-use. The active liquid effluent would be pumped to the active effluent treatment plant receipt tanks for processing. All other work clothing worn outside the active area would be sent off site to a commercial laundry.

7.4.8 Mechanical and electrical workshops and stores

The mechanical and electrical workshops and stores would serve both surface and underground requirements for the supply and maintenance of equipment. The workshops would be equipped with both mechanical and electrical plant servicing areas, and would have an overhead travelling crane (SWL approximately 20t). The stores would have a mobile racking system for small parts and an open area with an overhead crane for the larger items of equipment which require storage.

7.4.9 Administration and reception

The administration and reception building would provide the following:

- offices for staff engaged in managing the disposal facility, including senior managers, finance and accounts, IT, safety and environmental, training and corporate communications services
- cafeteria and restrooms
- conference and meeting rooms
- training facilities.

7.4.10 Visitor centre

A separate visitor centre would be provided outside the fenced site boundary. Facilities might typically include a reception area with a static exhibition and computer simulation of the disposal facility operation.
8 Underground structures and facilities

In order to develop the illustrative designs, a number of assumptions regarding the facility design and its operation have been made. Described in the following subsections are the facilities we envisage would be required to enable the transfer and emplacement of waste packages underground. It is recognised that the detailed design and configuration of these facilities would need to be developed as the project advances. At appropriate stages of development, the design would be reviewed as part of the iterative process for disposal system development.

8.1.1 Underground access

Access to the underground facilities would be via a combination of shafts and, potentially, drifts, depending upon the host geology. For the illustrative designs in a higher strength rock and lower strength sedimentary rock, access underground is assumed to be via a drift and three shafts constructed for ventilation and spoil removal. For evaporite rocks, access is assumed to be via four shafts. The final design will be based on the information collated during the surface-based investigation phase and the initial underground investigations. Designs for underground access will take account of the environmental impacts of operations, including package throughput, the depth of the disposal horizon and the geological characteristics of the overlying geology.

8.1.2 Drift

Drift access has been assumed for the illustrative designs in a higher strength rock and lower strength sedimentary rock. The entrance to the drift would be covered by a drift top building, which would provide a weatherproof structure for drift wagons and operational personnel awaiting final clearance to go underground. The building would be equipped with doors and other protection measures to allow only authorised drift trains (drift wagons and locomotives) with the correct rack and pinion profile to enter the drift.

The drift top building would also be the point where operational personnel passing into and out of the underground areas, via the drift, would be recorded. Combined with similar records from shaft number 1, this would provide an accurate record, at all times, of the number of personnel underground.

The drift is assumed to be constructed at an average gradient of 1:6, and would connect the surface waste transfer facilities with the underground disposal facilities. It would also serve as the air intake for the disposal area ventilation circuit.

The drift would be the principal means of access from the surface to the underground disposal facilities. Its primary functions would be:

- transport of waste packages and containers
- transport of large components
- transport of operational personnel
- export of liquid effluents
- a second means of egress from underground
- a route for services
- an intake airway for disposal ventilation.

The approximate length would be 4.0km, subject to the location of the underground disposal facilities in relation to the location of the surface facilities, allowing for changes in gradient at the start and finish.

The upper section of the drift is assumed to pass through high-permeability sedimentary strata, which would require pre-treatment to control groundwater inflows during construction. Groundwater control in the upper 10m or so of strata would be achieved by
de-watering. Thereafter, treatment by grouting from the surface would be carried out to the
maximum practicable depth of about 130m below ground level. Groundwater control for the
drift at depths in excess of this would be by conventional cover grouting techniques from
within the drift, and would form part of the excavation cycle.
A number of construction techniques are available for the drift including Road header and
drill and blast techniques. Starting from the surface, the first 60m length of the drift (10m
depth) would be constructed by cut-and-cover methods with a drift portal at the surface.
The remainder of the upper section of drift would be circular in cross-section, with an
assumed concrete hydrostatic pressure-resistant lining of 5.5m internal diameter.
Beyond 300m depth in the drift, it is assumed there would not be a requirement for a
hydrostatic pressure-resistant lining and that this lower section would require support in the
form of rock bolts, mesh and shotcrete. It is assumed that this section of the drift could be
driven upwards from underground to meet the tunnel from the surface. Access for this
lower section of the drift would initially be via a shaft. It is currently envisaged that there
would not be a requirement for a hydrostatic pressure-resistant lining in this section and
that this section would require only minimal ground support. The tunnel here would be
either circular or a ‘D’ cross-section, 5.5m wide by 5m high, depending upon the method of
excavation adopted.
An electrical substation and pumping station would be constructed about halfway down the
drift, to collect and remove any residual groundwater from the upper section. The design
would also incorporate an additional pumping station at the bottom of the drift and a sump
roadway to provide additional drainage storage capacity.
Where the drift is circular, the floor would be in-filled with concrete to support the rack-and-pinion rail system, and would incorporate a gravity drain. The drift would carry a number of services, including a 100mm diameter water main, 11kV power cables and a 100mm diameter pumping main for discharging uncontaminated groundwater and process water. Indicative cross-sections through the upper and lower drift sections are shown in Figure 16.
Once excavation, lining and support are complete, the rack and pinion rail system would be installed, capable of transporting loads of up to 80t.

The drift locomotives would be powered from overhead cables via a pantograph, and are currently assumed to be restricted to a maximum speed of 20km/h [33] (Figure 17). A separate carriage would be provided for the transport of up to 30 persons per journey. Personnel and waste transport packages would not be carried on the same journey.
There would be four basic types of drift wagon:
- wagon for transport packages only
- general-purpose wagon for plant, equipment and materials
- effluent tanker
- carriage for personnel.

Prior to first waste emplacement, the drift rail system would be used for the transportation of large, long and heavy mechanical plant and equipment for the inlet cell and disposal facilities.

Following the commencement of disposal, the drift would be designated a radiologically controlled area, with restricted use and access.

### 8.1.3 Shafts

The primary functions of the three shafts would be to:
- transport construction personnel underground
- provide personnel working underground with an alternative means of egress to the surface, in line with mining practice
- provide ventilation to the construction and operational areas underground
- provide an export route for excavated rock

All shafts are currently assumed to be sized at 8m finished diameter. This cross-sectional area will allow for the flexibility for the transport of plant, materials and people if required.

Shaft number 1 would be the principal means of access underground for personnel and materials, and act as the construction ventilation intake.

During construction, shaft number 2 would chiefly serve as the export route for excavated rock and also act as an air return for the construction ventilation system. The shaft would be equipped with a high-performance winding system to maximise its rock removal capacity.

Shaft number 3 would serve as a ventilation return shaft and as a means of egress from underground in an emergency. This third ventilation shaft in conjunction with the drift would enable separate ventilation of the waste disposal operations from the construction operations.
All shafts would be constructed with sumps for the installation of safety equipment (e.g. shaft bottom arrestors) and have a water storage capacity with pumps and pipe columns to the surface.

Where the shafts pass through high-permeability sedimentary cover strata, they would be lined with a hydrostatic pressure-resisting concrete lining. The bottom section of the shafts may not need a hydrostatic lining, but would have a concrete lining to give long-term integrity with minimal maintenance.

The design and appearance of the winding systems within the shafts and the shaft-top buildings and structures would be similar to those found at deep mines in the UK.

The headgear would be erected over the shafts, from which the shaft conveyances (cages or skips) would be suspended from wire ropes. An emergency mobile winder would also be available on site, giving cover for loss of power and the need to evacuate personnel from underground. The shaft systems would be based on relevant good practice and incorporate up-to-date control, monitoring and safety equipment to reduce the risk of and mitigate accident situations.

**Evaporite rock**

For the evaporite rock illustrative design, we have assumed that shaft-only access is viable; thus, the wastes will be transferred through one of these shafts (Figure 18). The entrance to this dedicated waste emplacement shaft would be within the coverage of the waste package transfer facilities, which would provide a weatherproof environment for shaft transfer wagons and emplacement personnel awaiting final clearance to go underground. The building would be equipped with doors and other protection measures to allow only authorised shaft transfer wagons to enter the site. The emplacement shaft top building would also be the point where emplacement operational personnel passing into and out of the underground areas, via the shaft, would be recorded. Combined with similar records from the construction shaft site, this would provide an accurate record, at all times, of the number of personnel underground.

**Figure 18  Simplified waste emplacement shaft**

![Figure 18 Simplified waste emplacement shaft](image)

Once excavation, lining and support are complete, the shaft system would be installed and be capable of transporting loads of up to 80t.

**8.1.4 Underground transport and handling**

In the illustrative designs, which are assumed to be constructed on a single level using an idealised layout, the underground emplacement rail system would split in two directions at the disposal facility level, with one branch going to the ILW/LLW disposal area and the other serving the HLW/SF disposal area.
In the higher strength and lower strength sedimentary rock illustrative designs, operational personnel would be transported down the drift in a dedicated personnel carriage. All construction personnel would be transported underground and be kept separate from the disposal areas underground. When underground, they would travel to the inlet cell area in a carriage hauled by a locomotive, and would disembark at a platform at the opposite side of the inlet cell from waste arrivals. The personnel platform would also provide access to the main underground control room. Personnel movements would only be allowed when there are no transfer wagons travelling underground in the drift carrying waste packages.

8.2 ILW and LLW handling and disposal

The ILW/LLW disposal area is currently assumed to consist of a series of disposal vaults suitably connected by transport tunnels for the disposal of UILW, SILW, LLW and DNLEU. The UILW would be transported to the inlet cell (Figure 19), where it would be remotely removed from its transport container and transported to the disposal vault via a designated access tunnel. The SILW and LLW would be transported to the SILW/LLW disposal vaults via access tunnels.

8.2.1 UILW handling and disposal

The inlet cell is where each UILW package would be removed from its shielded reusable transport container (SWTC) and placed on a bogie for transport to the designated vault. A schematic of the inlet cell suite is shown in section in Figure 19. It is assumed that the inlet cell design would be different for the higher strength rock when compared with the lower strength sedimentary rock and evaporite rock illustrative designs. Due to assumed conditions, the height of excavation for an inlet cell in a lower strength sedimentary and evaporite rock illustrative design is less than for the higher strength rock. The inlet cell would be located underground to enable the waste packages to be transported in their robust reusable transport containers as close as possible to the point of disposal. The cell would be shielded, and would also allow for the complete containment of any radioactive material in the unlikely event of an incident. In addition to the in-built redundancy and mechanism back-up that would be incorporated into the inlet cell cranes, a retrieval system would be provided so that the cranes could be hydraulically operated in the event of total electrical failure. Shielded viewing windows and CCTV would be provided to monitor all stages of the operations within the inlet cell.

The inlet cell design would be modular to ensure that maintenance, replacement and re-use of equipment and components would be relatively straightforward. Wagons containing UILW packages would arrive at the end of the container transfer line for offloading and, similarly, wagons containing disposal stillages would arrive at the end of the stillage transfer line for off-loading.

An SWTC containing a waste package would be removed from the wagon by crane and moved along the container transfer line and placed either directly onto the inlet cell process line bogie or into a small buffer store within the container transfer line. Control of waste disposal would be maintained through inventory tracking procedures. The crane lifting arrangements for the SWTC would be different from those for the SILW and LLW packages so as to prevent the possibility of inadvertently mixing waste packages in the vaults.

Once the SWTC with its contents is on the inlet cell process line bogie, it would enter a containment booth through a shielded airlock door and stop beneath the lid/seal unbolting machine. All transport containers would have common types of lifting and lid attachment features. Although the lids of the SWTC would be sealed, the packages inside would be vented to prevent gas pressurisation, and therefore there would be provision to remove any gases from the SWTC in a controlled manner. Measurements would be taken to ensure
positive ventilation of the container. Detailed procedures would be required to prove that the SWTC had been de-pressurised and any evolved gases discharged before releasing the main lid seal. Effluent gases would not be released into the booth, but would be collected, monitored and treated through the active ventilation system. The lid and seal would then be unbolted, but not yet removed.

The SWTC would enter the main shielded area of the inlet cell through shield doors. The inlet cell bogie would next stop beneath the lid lift machine. At this station, a grab would lower and engage the central lifting pin on the lid, and lift it clear of the SWTC body.

The inlet cell bogie would then move the SWTC along to the package transfer station and stop beneath the transport container containment shroud. The shroud would lower and seat on the exposed sealing face of the open SWTC. The purpose of the shroud is to limit the potential for contamination transfer during waste package handling operations, and also protect the sealing face against scratching. With the shroud in place, a shielded gate would open to the package transfer machine area above. Another shielded gate would then open to the adjacent waste package monitoring station. The package transfer machine would lower into the SWTC and engage the lifting features of the waste package.

**Figure 19  Simplified UILW inlet cell**

With the waste package engaged, the package transfer machine would lift the package clear of the transport container and traverse it to the monitoring station. This would release the empty transport container.

While the package is suspended from the package transfer machine, there would be an opportunity to confirm the scheduled identity of each individual package using CCTV cameras. The package transfer machine would then lower the waste package into the shielded monitoring station, and the shield doors would close, allowing waste package monitoring to commence. After monitoring, the package transfer machine would retrieve the package from the monitoring station and transfer it to a position above the closed shielded access hatch directly over the vault transfer tunnel.

If required, it would be possible to introduce a disposal stillage into the process via the stillage transfer line. This would be undertaken in parallel with the inlet cell operations. The stillage transfer line would have a 2t capacity monorail hoist. Disposal stillages would arrive in the reception area on a general-purpose drift wagon. The stillage hoist would collect a stillage from the wagon and move it to one of the two stillage buffer areas. When required, the same stillage hoist would pick up a stillage and place it on the transfer conveyor, to be moved through a containment booth to the stillage transfer station. After monitoring, the package transfer machine would individually transfer the four 500 litre drums out of the transport stillage and into the disposal stillage. At this point, the package transfer machine would transfer the complete disposal unit as detailed previously.
The package transfer machine would lower the disposal unit through the open shielded access hatch and onto a previously parked vault transfer tunnel bogie situated in the vault transfer tunnel. The vault transfer tunnel bogie would travel by a direct route from here to the entrance to the vault, where a system of shield doors would be arranged to allow the transfer of packages from the transfer tunnel bogie and either onto a remotely operated overhead crane or a remotely operated stacker truck.

With the contents of the reusable transport container removed and the shield gates closed, the containment shroud would be raised. The inlet cell bogie with the empty transport container body would then be moved back to the lid-lifting station, where the lid would be replaced. The inlet cell bogie would then move back through the shield doors, to the lid-bolting station, and the lid would be bolted down.

The bogie would then move the empty container back through the interlocked shield door to the transfer station, to allow monitoring of all external surfaces. If the container passed the monitoring tests, it would then be removed from the inlet cell containment area by the overhead crane, via the container transfer line, and placed onto an empty transfer wagon for return to the surface.

If the monitoring indicated the container required decontamination followed by further monitoring, the bogie would park at the monitoring transfer station, where a crane would take it into a monitoring and decontamination area located parallel to the container transfer line (off-line from ongoing inlet cell operations). There, the external surfaces of the container would be monitored by swabbing, and decontaminated where necessary using manual techniques. Following decontamination and confirmatory contamination monitoring, it would be moved by the crane and placed onto an empty transfer wagon for return to the surface.

The inlet cell would include a facility for package inspection as well as for monitoring and decontamination of each outgoing empty reusable transport container. To achieve the required throughput, these operations would take place in parallel with unloading operations of the next incoming transport container.

The container transfer line would have an 80t SWL overhead travelling crane for lifting and moving packages.

Another 20t SWL travelling crane would be mounted in the roof space of the inlet cell excavation, and would be able to access all parts of the inlet cell facility. It would be used for the installation of the cell and subsequently to handle spares and equipment throughout its service life. The same crane could also be utilised to aid the recovery of waste packages from the package transfer machine area, should this ever be required.

The design of the inlet cell stations would allow easy access to the craneage above for maintenance. A tool change area would be provided through shield doors, so that the grab on the package transfer machine could be changed to accommodate different types of waste packages.

The inlet cell would be provided with its own ventilation plant room. Air would be drawn in from the reception area, through control dampers, coarse filters and high-efficiency particulate air (HEPA) filters, before being ducted to each of the cell compartments. The discharge route would be into the vault transfer tunnel, via HEPA filters, non-return dampers and fire dampers, all of which would be accessible from outside the inlet cell. The dampers are required to prevent any back-flow from the downstream facilities, including the UILW vaults.

This inlet cell design would provide facilities for occasional internal contamination checks on empty transport packages. More-intensive internal monitoring might well be required during commissioning, but it has been assumed that confidence could be gained that containers would be free from significant internal contamination. It has been assumed that, during normal operations, approximately one in 10 containers would be internally monitored at the inlet cell, for sampling purposes and to ensure that external quality control is being maintained. This would be carried out off-line from the inlet cell operations, where a crane
would transfer the empty transport package to the monitoring and decontamination area. Following monitoring, and if necessary decontamination, the crane would transfer the empty transport package to a wagon for return to the surface.

The decontamination cell and active maintenance workshop for the transfer tunnel bogies would be situated at the end of the transfer area. This facility would also be the main route for equipment arriving down the drift to enter the transfer tunnel and the UILW vaults beyond.

Monitoring and decontamination of transfer tunnel bogies would take place before routine maintenance, or if it was ever suspected that they had become contaminated. Other equipment exiting the transfer tunnel (e.g. maintenance equipment) would also be monitored and decontaminated within this cell. The bogie decontamination cell would consist of a parking position for the bogie and access for decontamination operations. Decontamination would be undertaken by swabbing or high-pressure water hoses. Adjacent to this cell would be an active workshop with an overhead crane, workbenches and other facilities for hands-on maintenance of equipment from the active areas, particularly the bogies.

The UILW would be delivered in a range of package types, including disposal stillages holding four 500 litre drums, and individual 3 cubic metre drums, 3 cubic metre boxes and MBGWS boxes. UILW waste packages would be transported from the inlet cell to the vaults via a common transfer tunnel.

Although the basic handling principles are considered to be common to all illustrative designs, due to the different host rock properties the size and excavation of disposal vaults will be different, and this could require different handling configurations from those currently detailed.

**Higher strength rock – UILW emplacement**

The UILW disposal vaults are assumed to have a cross-section of approximately $16m \times 16m$ (Figure 20) and an effective length of approximately $300m$ [11]. For the Baseline Inventory, 19 disposal vaults would be built to accommodate UILW packages.
Disposal would start from the far end of the vault, and work back towards the access hatch. The basic stack arrays in the vaults would be as follows:

- 500 litre drum stillages would be stacked in arrays seven wide and seven tall
- 3 cubic metre boxes and drums would be stacked six wide and seven tall
- MBGWS boxes would be stacked six wide and six tall.

Emplacement within the vaults would be by an overhead travelling crane running the full length of the vault (Figure 21).

The placing of the disposal units in the vault would be controlled such that units could be positioned about a common reference point. Laser control of crane movements is a proven system that could be employed; detailed design would refine this element based on the proven technology at the time.

At the end of each UILW disposal vault there would be a crane maintenance area that would be shielded from the waste by a mobile shield door. This would provide a safe means of accessing the emplacement crane for maintenance and breakdown repair.

Reliability of the disposal crane would be essential to vault operation, so the design would incorporate redundancy and mechanical back-up. To deal with the unlikely event of total crane systems failure, a retrieval system would also be provided to enable the crane to be pulled back to the maintenance area. In case the crane failed while a package was still hoisted, facilities would be provided to operate the lowering mechanisms directly after the crane had been pulled back immediately to the other side of the shield door. This would enable allow retrieval and repair of the crane.
Lower strength sedimentary rock – UILW emplacement
The UILW disposal vaults are assumed to have a cross-section of approximately 9.6m wide \times 11.5m high (Figure 22) and an effective length of approximately 100m (Drawing E/DRG/0041052). For the Baseline Inventory, 169 disposal vaults would be built to accommodate UILW packages.

Figure 22  Schematic cross-section through an UILW vault – lower strength sedimentary rock
Disposal would start from the far end of the vault, and work back towards the access hatch (Figure 23). The basic stack arrays in the vaults would be as follows:

- 500 litre drum stillages would be stacked in arrays three wide and five tall
- 3 cubic metre boxes and drums would be stacked three wide and five tall (as illustrated above)
- MBGWS boxes would be stacked two wide and five tall.

The emplacement operation and the crane facilities would be similar to those described for UILW in the illustrative design for higher strength rock.

**Figure 23** UILW emplacement and retrieval system in a lower strength sedimentary rock

Evaporite rock – UILW emplacement

The UILW disposal vaults are assumed to have a cross-section of approximately 10m wide × 5m high (Figure 24). The effective length of the vault would be 100m, and each module would comprise eight vaults, giving an available vault length of 800m. For the Baseline Inventory, 167 vaults would be built to accommodate packages arranged in groups of eight each.

**Figure 24** Schematic cross-section through an UILW vault – evaporite rock

Disposal would start from the far end of the vault, and work back towards the front of the disposal vault utilising a stacker truck (Figure 25). The basic stack arrays in the vaults would be as follows:
• 500 litre drum stillages would be stacked in arrays five wide and three tall
• 3 cubic metre boxes and drums would be stacked five wide and three tall (as illustrated above)
• MBGWS boxes would be stacked five wide and three tall.

**Figure 25** UILW emplacement and retrieval system in an evaporite rock

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### 8.2.2 SILW/LLW handling and disposal

SILW would be delivered in a range of packages, and comprise 4 metre boxes, 2 metre boxes and WAGR boxes. LLW is currently assumed to be packaged in 4 metre boxes. SILW and LLW packages would be delivered underground to the SILW/LLW reception area. They would be unloaded by an overhead travelling crane into the SILW/LLW temporary storage area, ready for disposal in the vaults. Because the rate of arrival of SILW and LLW packages would be much lower than that of UILW, it would be justifiable to store sufficient numbers of packages in an underground temporary storage area, to allow disposal to take place in campaigns. The throughput of SILW and LLW packages for the Baseline Inventory volume would be some 143 disposal units per year, assuming a constant rate over the 50-year disposal period.

SILW and LLW package handling would be by a 65t capacity manually operated stacker truck in all geologies, which would transport the packages along the vault and stack them at the disposal face. Design development work has also looked specifically at the options for package-handling systems within these SILW/LLW disposal vaults. Following safety assessment, alternative systems may provide better solutions; however, this would depend on the configuration and size of the vaults and the ease of retrievability required.

#### Higher strength rock – SILW/LLW emplacement

An SILW/LLW disposal vault of cross-section about 16m wide × 15m high (Figure 26) is assumed, and each would be 300m long (Drawing E/DRG/0041002). Due to the stacker truck manoeuvring, the vault would have an effective length of 265m. There would be a requirement for six SILW/LLW vaults to dispose of the Baseline Inventory.

The SILW/LLW disposal vaults would be filled in a similar manner to the UILW disposal vaults, in arrays across the vault cross-section, starting from the far end. Package handling would be by a single manually driven, rubber-tyred stacker truck, free-steered (as opposed to running on fixed rails or guides) and with a capacity of 65t. This would transport the packages along the vault and stack them at the disposal face. The driver’s cab may be shielded and air-conditioned, including HEPA filtration to provide protection in the event of any release of radioactive particles from a dropped package.

Disposal would start from the far end of the vault, and work back towards the entrance. The basic stack arrays in the vaults would be as follows:
WAGR boxes would be stacked in arrays four wide and five tall
4 metre boxes would be stacked three wide and five tall
2 metre boxes would be stacked five wide and five tall.

**Figure 26  Schematic cross-section through SILW/LLW vault – higher strength rock**

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**Lower strength sedimentary rock – SILW/LLW emplacement**

A SILW/LLW disposal vault is assumed to have a cross-section 9.6m wide × 11.5m high (Figure 27), with an effective length of 100m long (Drawing E/DRG/0041052). There would be a requirement for 77 SILW/LLW disposal vaults to dispose of the Baseline Inventory. The SILW/LLW disposal vaults would be filled in a similar manner to the UILW vaults, in arrays across the vault cross-section, starting from the far end, taking waste packages in the form of 4 metre boxes stacked in arrays. Package handling would be by a single manually driven, rubber-tyred stacker truck, free-steered (as opposed to running on fixed rails or guides) and with a capacity of 65t. This would transport the packages along the vault and stack them at the disposal face. The driver’s cab may be shielded and air-conditioned, including HEPA filtration to provide protection in the event of any release of radioactive particles from a dropped package.

Disposal would start from the far end of the vault, and work back towards the entrance. The basic stack arrays in the vaults would be as follows:

- WAGR boxes would be stacked in arrays two wide and three tall
- 4 metre boxes would be stacked one wide and three tall
- 2 metre boxes would be stacked two wide and three tall.
Evaporite rock – SILW/LLW emplacement

A SILW/LLW vault module is assumed to comprise seven vaults, each 90m long and with two tunnels connecting the end of the vaults, each 225m long (Figure 28). The cumulative vault length for disposal in each module would be 1,080m, with a vault cross-section assumed to be 10m wide × 5.5m (Drawing E/DRG/0041109). There would be a requirement for 38 SILW/LLW disposal vaults for the Baseline Inventory.

The SILW/LLW disposal vaults would be filled in a similar manner to the UILW vaults, in arrays across the vault cross-section, starting from the far end, taking waste packages in the form of 4 metre boxes stacked in arrays. Package handling would be by a single manually driven, rubber-tyred stacker truck, free-steered (as opposed to running on fixed rails or guides) and with a capacity of 65t. This would transport the packages along the vault and stack them at the disposal face.

Disposal would start from the far end of the vault and work back towards the entrance. The basic stack arrays in the vaults would be as follows:

- WAGR boxes would be stacked in arrays four wide and two tall
- 4 metre boxes would be stacked two wide and two tall
- 2 metre boxes would be stacked four wide and two tall.

Due to the creep properties of the host rock, construction would take place on an as-required basis, and two or three tunnels could be under construction and fit-out at any one time, due to their length. The layout of the disposal facility would allow for the construction of the subsequent SILW/LLW disposal vaults as required.
8.2.3 ILW/LLW support facilities

There would be a number of additional support facilities in the ILW/LLW disposal area. A sampling laboratory would house equipment to allow checks on chemistry and radioactivity concentrations within any collected groundwater. This would sample the effluent sited in the receipt and dispatch cell prior to its dispatch to the surface.

The effluent receipt and dispatch cell would contain the collection tanks for liquid effluents arising within the active areas, and the pumps and valves needed to circulate and export the liquid to the tanker-filling station located in the inlet cell complex.

The SILW/LLW temporary storage area would be required, as the SILW and LLW packages would arrive at an average rate of less than three per week. They would be stored underground until a sufficient number had accumulated for an efficient campaign of disposal. Off-loading of SILW and LLW packages from drift wagons into the temporary storage area would be by a SWL 65t overhead travelling crane. This crane would also incorporate a package-weighing facility, to obtain the data necessary for planning the safe stacking of mixed types of SILW and LLW packages.

The vault garage would house the stacker truck used for SILW and LLW disposal and also UILW disposal in the evaporite rock illustrative design. To allow maintenance of this truck, a garage area would be integrated into the SILW/LLW disposal vault access roadway. This would include all the necessary workshop facilities to undertake maintenance, including a crane, workbenches, stores, etc. It is proposed to use a battery-powered or electrically powered stacker truck.

8.3 HLW and SF handling and disposal

The HLW/SF disposal area consists of a series of disposal tunnels that are connected by transport tunnels. The disposal canisters would be transported underground in a DCTC [30] to the transfer station, where the DCTC shock absorbers would be removed.

The disposal canister would then be transferred into the deposition machine (higher strength rock illustrative design) and transported to the disposal tunnels. In the illustrative designs for lower strength sedimentary rock and evaporite rock, it is assumed that the
disposal canister would remain inside the DCTC and be taken directly to the disposal
tunnel reception area, where the disposal canister would be removed from the DCTC and
transferred into the deposition machine for emplacement.

**Higher strength rock – HLW/SF emplacement**

The HLW/SF disposal area would consist of disposal tunnels designed for in-tunnel vertical
emplacement of individual disposal canisters within deposition holes (Figure 29). Each
disposal tunnel is assumed to be single entry (dead end), and would be nominally 340m
long with an effective disposal length of 310m and dimensions of 5.5m wide × 5.5m high
[23]. There would be a 150mm-thick concrete floor to allow for a uniform base. Ten
disposal tunnels would be grouped together to form a disposal area. It is currently assumed
that a 50m barrier pillar would separate disposal areas, and tunnels would be constructed
at 25m centres [23].

The layout of the disposal tunnels together with their service tunnels would be rectangular
in shape. The service tunnels would have a ‘D’-shaped cross-section with an arched roof,
and would vary in cross-section from 5.5m wide x 5.5m high to 7m wide x 7m high [23].

It is assumed that each disposal tunnel would accommodate 48 deposition holes spaced at
6.5m centres. However, it is assumed that approximately 8% of these deposition holes will
be lost due to groundwater inflow, etc. [23]. Different-depth holes would be drilled to
accommodate the different-length disposal canisters and the associated mass of pre-
compacted bentonite buffer.

A total of 296 disposal tunnels would be required to dispose of the Baseline Inventory, and
these are shown in Drawing E/DRG/0041002.

The disposal canister is removed from the DCTC in the transfer hall. The DCTC would be
turned to the vertical orientation and lowered into the pit in the transfer hall floor using the
overhead crane (SWL 60t), where the lid would be unbolted but not removed. The
deposition machine would be located above the pit, and the gamma gate tilted so that the
shielded tube was orientated in a vertical direction. The shielded tube would be lowered to
a position where the bottom is slightly above the DCTC, and the lid of the DCTC would be
removed by a rolling table. The hoist on the deposition machine would be moved over the
tube, and the hoist tool and the docking device lowered and connected to the grapple unit
of the disposal container. The grapple unit would be disengaged from its recess inside the
tube, and lowered through the shielded tube into the cask, and the disposal canister lifted
from the DCTC into the shielded tube. The shielded tube would then be elevated, and the
disposal canister tilted to the horizontal direction. The operations would be supervised with
a TV camera inside the pit. The camera would also be used for identification of the disposal
canister and observation of possible damage. The empty DCTC would be inspected
internally for damage, and the lid applied. The lid bolts would be inserted and tightened,
and the transport cask lifted up from the pit, and tilted and placed in a park position. The
DCTC would be further inspected for contamination, with inspection of the bolts, trunnions
and general outer surfaces. The shock absorbers would then be fitted, and the DCTC
placed on a drift wagon for return to the surface.

A maintenance area would be provided at one end of the facility (where the deposition
machine would normally enter) to allow routine maintenance and repair of the deposition
machine. This would include removal of the shield tube for decontamination and repair as
well as general maintenance to the other components of the deposition machine.

The deposition machine (Figure 29) would transport the disposal canister to the disposal
tunnel, where the deposition machine would be located in the correct position over the
selected deposition hole, which would have been prepared with bentonite blocks and rings
before emplacement of the disposal canister (Figure 30). The pre-compacted bentonite
blocks and rings would have been transferred down the drift and transferred from the rail
car to the disposal tunnel using a dedicated hoist mounted on the deposition machine. A
base block and a number of rings (depending on the type of disposal canister) would be
placed in the disposal hole.
The mobile part of the shielding would be lowered to the tunnel floor, and the shield tube tilted to the vertical and lowered down into the disposal hole. The disposal canister would then be lowered into the deposition hole and surrounded by bentonite rings. A further three bentonite blocks would be retained within the deposition machine for placement following the emplacement of the disposal canister. After all holes in a disposal tunnel are filled, backfill is used to fill all void space and a tunnel seal is set.

It should be emphasised that the description of processes is high level at this stage and associated drawings are simplified. At this stage, the aim is to focus on layout aspects as, according to current plans and emplacement of such waste would not occur until about 2075, by which point extensive emplacement experience should have been gained in several other national programmes.

**Figure 29   Deposition machine**
Lower strength sedimentary rock – HLW/SF emplacement

The HLW/SF disposal area would consist of a series of disposal tunnels connected by transport tunnels from the drift for the disposal of HLW, SF, plutonium and HEU. These disposal tunnels would be designed for the horizontal disposal of individual disposal canisters on top of a layer of bentonite blocks. It is currently assumed that each disposal tunnel would be nominally 800m long and 2.5m in diameter. However, the entrance to the disposal tunnel (first 20m) would be considerably larger, 5.6m wide × 3.8m high, to allow for the transfer of the disposal canister from the DCTC onto bentonite blocks that would have been pre-placed onto a disposal trolley. There would be a concrete floor to provide a uniform base, and each disposal tunnel would be constructed at 40m centres.

A total of 99 disposal tunnels would be required to dispose of the Baseline Inventory, and these are shown in Drawing E/DRG/0041052.

Two interlocking shield doors would be provided at the reception area of the disposal tunnels, one at the entrance to the reception area and one at the entrance to the disposal tunnel. With the inner door closed, the outer gate would be opened, and the disposal trolley and its power unit would enter the reception area and be aligned with the disposal tunnel.

On arrival underground, the DCTC would be taken to a transfer hall, where the shock absorbers would be removed and the DCTC transferred to a transfer wagon. From here, the DCTC would be moved into the disposal tunnel reception area, on a parallel track to that accommodating the disposal trolley. A dedicated reception area would be provided at each of the disposal tunnels, equipped with shield doors at both ends to provide protection to personnel. All transfer operations would be undertaken with shielding provided. The underground layout would be designed to allow the drift locomotives and wagon direct
access to all disposal tunnel reception areas. This would be arranged so that the drift wagon would enter the reception area in front of the drift locomotives.

The lid bolts would be removed but the lid would be left in position; and the outer shield door closed. The process of transferring the canister from the DCTC onto the bentonite blocks would then be undertaken. For this operation, the DCTC lid would be removed and the disposal canister moved out horizontally onto the support bed, which would be fitted with a side transfer capability to allow the disposal canister to be moved onto the bentonite support blocks located on the transfer trolley. During this operation, cameras mounted on the support bed would be used for identification of the disposal canister and observation of possible damage. Once transfer to the disposal trolley is completed, the shield door to the disposal tunnel would be opened, and the disposal trolley would transfer the disposal canister and support blocks to the required location in the disposal tunnel. The disposal canister and supporting bentonite blocks would be lowered as a unit to the floor of the disposal tunnel and released from the trolley (Figure 31). The disposal trolley would be withdrawn back to the reception area, and the inner shield door closed. The empty DCTC would be inspected internally for damage, and the lid fitted, before being returned to the transfer hall and subsequent delivery to the surface.

The mobile bentonite hopper would be delivered into the reception area; all personnel would leave the reception area, and the outer gate would be closed. The inner gate would be opened, and the hopper would enter the tunnel, straddle the canister and proceed to place pre-compacted bentonite pellets. The shield doors would be closed until the next disposal canister is emplaced. Once complete, the hopper would be removed from the tunnel. The process would be repeated after each disposal canister, to provide progressive backfilling of the disposal tunnel.

The disposal canister placement cycle would be repeated until the disposal tunnel is filled with disposal canisters. It is assumed that each disposal canister would be placed 3m apart from the previous canister.

Figure 31  Schematic of a HLW/SF disposal tunnel – lower strength sedimentary rock

Evaporite rock – HLW/SF emplacement

The HLW/SF disposal area would consist of a series of disposal tunnels suitably connected by transport tunnels from the waste emplacement shaft for the disposal of HLW, SF, plutonium and HEU. These disposal tunnels would be designed for horizontal disposal of individual disposal canisters on the floor of the disposal tunnel. Each disposal tunnel is assumed to be nominally 800m long × 4.5m wide × 3.5m high. However, the entrance to the disposal tunnel (first 20m) would be larger (6m wide × 5.5m high), to accommodate the transfer of the disposal canister from the DCTC onto the disposal trolley. Each disposal tunnel would be separated by approximately 40m of rock.
A total of 99 disposal tunnels would be required to dispose of the Baseline Inventory. The underground layout for the Baseline is shown in Drawing E/DRG/0041102.

In operation, the shock absorbers would be removed from the DCTC in the underground transfer facility. A dedicated reception area would be provided at the end of each of the disposal tunnels, equipped with shield doors at both ends to provide protection to personnel. With the inner door closed, the outer gate would be opened, and the disposal trolley and its power unit would enter the reception area and be aligned with the disposal tunnel.

At the reception area to the disposal tunnel, the transfer wagon carrying the DCTC would be moved into the reception area, on a parallel track to that accommodating the disposal trolley, and the locomotive would be disconnected and removed from the reception area. The DCTC lid bolts would be removed but the lid would be left in position; all personnel would be withdrawn, and the outer shield door closed. The DCTC lid would be removed, and the canister withdrawn from the DCTC, horizontally, onto the support bed. During this operation, cameras mounted on the support bed would be used for identification of the disposal canister and observation of possible damage. The empty transport container would be inspected internally for damage, and the lid applied.

The shield door to the disposal tunnel would be opened, and the disposal trolley would transfer the disposal canister to the required location in the disposal tunnel. The disposal canister would be lowered to the floor of the disposal tunnel (Figure 32) and released from the trolley. The disposal trolley would be withdrawn to the reception area and connected to the power unit, and the inner shield door closed.

The outer shield door would be opened, and the disposal trolley and its power unit would be transferred to the facility, to allow loading of the disposal canister.

The DCTC lid bolts would be inserted and tightened, and the DCTC would be further inspected for contamination, with inspection of the bolts, trunnions and general outer surfaces. The shock absorbers would be fitted, and the DCTC would be returned to the surface, utilising the shunter and transfer wagon.

The area of the disposal tunnel around the disposal canister would be filled with crushed rock salt, (from the surface rock crushing plant), immediately after placement of the disposal canister. The crushed rock salt would be transferred to a mobile hopper. The mobile hopper with a locomotive attached would be transferred to the reception area of the disposal tunnel, and the outer shield door closed remotely.

The inner shield door would be opened, and the mobile hopper would be detached from the locomotive and moved to the far end of the disposal tunnel, over the disposal canister that had just been emplaced. The crushed rock salt would be discharged, to fill the area beyond the disposal canister, and would then be gradually withdrawn to fill the area all around the disposal canister.

The mobile hopper would then be withdrawn to the reception area, connected to the locomotive, and the inner shield door closed.

The outer shield door would then be opened, and the locomotive and mobile hopper would be moved, to allow the disposal canister to be emplaced. The outer shield door would be closed until the next disposal canister is emplaced.

The above cycle would be repeated until the disposal tunnel was filled with disposal canisters, and crushed rock salt fills the remaining voids. It is assumed that disposal canisters would be placed 3m from the previous canister. Once all of the disposal canisters have been placed within a disposal tunnel, a tunnel seal will be constructed.
8.4 Plutonium and uranium handling and disposal

The operations for DNLEU waste packages would be identical to those for UILW waste packages, with the waste packages being processed through the inlet cell and via the transfer bogie to the UILW disposal vaults. These would then be emplaced using the remotely operated crane in the higher strength and lower strength sedimentary rock illustrative designs, and a remotely operated shielded stacker truck in the evaporite illustrative design.

The operations for plutonium and HEU would be identical to those for HLW and SF disposal canisters. Appropriate security arrangements would be put into place for all operations involving plutonium and HEU, in accordance with Office for Civil Nuclear Security (OCNS) guidelines.

8.5 Illustrative underground layouts

The illustrative layout of a GDF is based on construction of the disposal facility on a single level underground. We recognise that this is only an assumption used for the purpose of developing the illustrative designs, and any detailed site-specific designs could result in an alternative layout that could influence the size of the required facility footprint. These layouts have been based on idealised spacings between the packages within the disposal vaults. If further research showed the packages could be placed closer together, then it is conceivable that the footprint would decrease.

For the higher strength rock, the footprint for the Baseline Inventory would be approximately 5.6km² (Figure 33).
Figure 33  Illustrative underground layout in a higher strength rock for the Baseline Inventory

For the lower strength sedimentary rock illustrative design, the footprint for the Baseline Inventory would be approximately 10.3km² (Figure 34).

Figure 34  Illustrative underground layout in a lower strength sedimentary rock for the Baseline Inventory
For the evaporite rock illustrative design, the footprint for the Baseline Inventory would be approximately 8.8km$^2$ (Figure 35).

**Figure 35** Illustrative underground layout in a bedded salt for the Baseline Inventory

A full breakdown of the illustrative design footprints for the different geological settings and the inventory scenarios is provided in Appendix E. The implications of addressing additional wastes and the associated illustrative footprint layouts are considered in Section 14.
9 Infrastructure and services
In developing the illustrative designs it has been required to consider the infrastructure and services necessary to support operations at a GDF. The following subsections detail the provisions currently envisaged for the outline layout previously presented. These details could vary for specific sites – e.g. one in a coastal setting with its own harbour etc.

9.1 Surface infrastructure

9.1.1 Exterior lighting
There would be three types of exterior lighting on the site: operational, amenity and security.

- Operational lighting would be required so that operations could be carried out in a safe manner. For example, the stockyards would have a relatively high level of lighting to illuminate working areas.
- Amenity lighting would be provided for access roads and car parks. Footpaths would also be illuminated at low level by lighting bollards.
- For security reasons, the fence around the active area would be illuminated. Other sensitive areas would also be illuminated. Ideally, the outer perimeter fence around the whole site should also be illuminated, but it is recognised that this may not be possible for reasons of off-site environmental impact.

Particular care would be taken in the specification and siting of all surface lighting in order to minimise light spillage outside of the site without compromising safety and security. A screening bund around the site could also be designed to help to minimise light pollution.

9.1.2 Drinking water
A drinking water supply and on-site storage piped distribution system would be provided. The source of supply could be from an existing local utility water supply network, assuming the water pressure and quantity required were acceptable. Alternatively, it may be necessary to upgrade an existing system in order to provide an adequate supply to the site.

A storage tank would be provided on site, of sufficient capacity to ensure 24 hours emergency supply in the event of a failure in the normal supply.

9.1.3 Site drainage
The surface water drainage system would be designed to cater for the likely effects of climate change and in accordance with current practice, with due consideration for topography and the local drainage regime. To cater for more extreme rainfall events, e.g. a ‘once in 10,000 years’ storm, the site roads would be laid to falls or spillways provided so that surface water run-off would be discharged to either existing water courses or to lower lying land, to prevent the site from flooding. Shaft accesses would be covered and laid to fall from the access point, to avoid the inundation risk in storm conditions. For non-active surface areas, a sustainable drainage system would be designed, with due consideration of topography and the local drainage regime.

Where required, the surface water run-off would be passed through local oil and silt interceptors before being discharged to a water dispatch facility for testing prior to discharge or disposal. That facility would typically consist of multi-bay settlement tanks, oil interceptors and storage tanks, with arrangements for chemical conditioning should this be necessary. The plant would handle all surface water drainage and non-active drainage pumped from underground.

Regular sampling and monitoring would be undertaken to ensure that the quality and quantity of the effluent complies with the discharge consent. For certain parameters, such as pH or radioactivity, an alarm would be activated in the control room; at the same time,
an automatic valve would close, diverting the discharge to a non-compliance holding tank within the facility where the effluent would be stored until the situation was rectified. The effluent would then either be treated appropriately on site before being discharged or, if necessary, it could be taken off site by road or rail tanker for specialised treatment and disposal.

The treated effluent would be discharged from the site to a suitable drainage network or local watercourse, as agreed with the local authority and/or the appropriate environment agency. Discharges to local watercourses would be limited to the 'green field' run-off rate. If necessary, suitable balancing facilities would be constructed to ensure that this requirement can be met.

Foul water from the washing and changing facilities, toilets, etc., would be collected by a system of pipes and, then, either connected to an existing local utility foul drainage network nearby for off-site treatment or, if that is not feasible, it could be collected and treated on site in a packaged sewage treatment plant, the treated effluent then being discharged off site.

Regular sampling and analysis would be undertaken to ensure that the effluent quality meets the required standards before discharge. The treated effluent would be discharged from the site to a suitable drainage network or local watercourse, as agreed by the local authority and/or the appropriate environment agency.

9.2 Underground infrastructure - common services area

The underground facilities that would support the construction phase of the facility as well as being required for the disposal operations would be located in this area, termed the 'common services area'. They would consist of a number of facilities, which are identified below.

9.2.1 Construction area link

This facility would be located at the base of the drift in the higher strength and lower strength sedimentary rock illustrative designs and at the base of the waste transfer shaft in the evaporite rock illustrative design. This facility would allow the delivery of large construction items. Facilities would be provided to check for any potential contamination of the waste transfer wagon and contents before they entered the construction area. A runway beam would be provided for off-loading from the wagons onto construction area transport vehicles.

9.2.2 Construction ventilation plant room

Fans installed in an underground roadway would ventilate the construction circuit of the GDF. This room would be near shaft number 1, which forms the construction air intake. The fans would force air around the construction roadways, creating a positive pressure with respect to the disposal air circuit, which would operate below atmospheric pressure.

9.2.3 Workshops and storage

The workshops and storage hall would provide an area where vehicle repair and maintenance could be undertaken. This facility would be required for all phases of construction, operation and closure. This facility would also include a place for storage of materials and vehicle/plant spares.

9.2.4 Personnel hall

The personnel hall provides a rest area for staff during the shift, and would be required during the construction and disposal phases. It would also provide a safe area with additional self-rescuer facilities in case of an emergency. The facility would require an electrical supply, sanitary facilities, environmental monitoring equipment and an airlock.
This facility would be located off the primary transport tunnel and close to the workshops/storage hall and electrical substation.

9.2.5 Vehicle hall

Vehicles used during the construction phase would be housed in a dedicated hall when not in use. This hall would be located close to the drift or waste emplacement shaft in the evaporite illustrative design, and would require a power supply for maintenance work, a crane, lighting, vehicle recharging and workbenches.

9.2.6 Battery-charging area

A battery-charging area would be provided for charging the battery locomotives or free-steered vehicles used in the underground transport system in the construction areas.

9.2.7 Free steered vehicle/locomotive garage

This facility provides for free steered vehicle and locomotive maintenance and repair. Typical requirements would be electrical and mechanical workshops, cranes and jacking apparatus, vehicle-washing bays and controlled collection of water run-off. This facility would be sited close to the workshops/storage area, vehicle hall and battery-charging area.

9.2.8 Spoil bunker

An in-line rock bunker facility would be constructed near shaft number 2. This would act as temporary storage for excavated rock, to regulate the feed to the shaft. The bunker would also permit shaft downtime to be accommodated without necessarily stopping vault and roadway construction. The bunker capacity would be about 2,000m³.

9.2.9 Mines rescue room

The mines rescue room would form a combined fire station and mines rescue facility as well as a safe haven, if required. It is anticipated to contain a communication system, first aid facilities, stretchers, breathing apparatus, a lamp room, self-rescuers, and changing rooms and showers.

9.3 Ventilation and drainage systems

A number of different ventilation and drainage systems would be necessary for a GDF. These would include systems for the ventilation and drainage of the nuclear facilities on the surface, and the normal provisions for ventilation and air conditioning of modern buildings. Where feasible passive ventilation and heating/cooling systems would used for the surface facilities. However, the most significant ventilation system would be that provided for the underground areas. A summary of the ventilation design, and its requirements for the different disposal areas, is provided below. More detailed information on the ventilation system design for our illustrative designs is provided in [40].

The purpose of the underground ventilation systems would be to provide adequate ventilation for both waste disposal and construction activities throughout the life of the facility. The standards used for the design of the ventilation system must necessarily be a combination of good practice in the nuclear industry and in mining. The system must:

- Ensure that the manned operational areas have an acceptable working environment, commensurate with both nuclear and mining/construction regulations.
- Segregate the disposal ventilation circuit from the construction ventilation circuit. This would include air lock doors between the two areas.
- Achieve suitable environmental conditions in the vaults and tunnels to maintain the integrity of the waste packages for as long as necessary until they are backfilled. As part of this, the ventilation system must also prevent the build up of explosive and noxious gasses (such as hydrogen and methane) and radioactive gases (such as carbon₁₄, tritium and radon).
• Provide adequate ventilation flows for the construction activities, which may generate dust and fumes.
• Provide suitable filtration.
• Ensure ventilation moves from areas of low potential for contamination to areas of higher potential for contamination.

Segregation of the construction and waste disposal ventilation circuits would be an important feature of the design. It ensures that any airborne contamination from the waste disposal areas would not be drawn into the construction areas, and that dust and fumes generated by the blasting and excavation work would not be drawn into the disposal areas where they could affect the operational equipment.

This segregation would be achieved by using all four underground access routes (the drift and three shafts) as ventilation routes. In addition, the location of the intakes (drift and shaft number 1) and returns (shaft numbers 2 and 3) would further ensure that intake air should not be contaminated from exhaust sources. Prevailing wind factors and the location of potential fire sources would be taken into consideration.

Intake fans would be installed close to the base of shaft number 1, to force the air into the construction areas and to ensure that the construction areas remain at a positive pressure relative to the waste disposal areas. The waste disposal area ventilation would be supplied solely by the exhaust fans at the top of shaft number 3, keeping the whole area at a negative pressure, relative to both the surface atmosphere and, more importantly, the construction areas. The pressure differential between the construction and disposal ventilation circuits plays an important role in maintaining segregation of air streams. It would also ensure that under fan fault conditions the system would fail to safe, and that disposal air could not enter the construction side of the operations.

An active ventilation plant would be located at the surface within the main waste emplacement building complex. All discharges would be led to the atmosphere through a stack located at the side of the complex. Equipment would be in place to monitor quantities of dust, aerial contaminants, gases and radionuclides. Systems would also be in place to mitigate these releases, if any were identified.

The ventilation would play an important role in controlling the propagation of fires underground. The ventilation design is based on good practice, and segregates the flows to the construction and disposal sides of the facility. However, the effects of fires may change the ventilation flow patterns, or may invoke an intended change to control an incident. Fire hazards would need to be identified, and appropriate design changes or emergency responses implemented.

9.3.1 Ventilation – ILW/LLW disposal area

The air that ventilates the waste disposal areas would enter via the drift and flow through the manned areas and into the vaults via ducted, filtered and damped systems, to allow control and monitoring of the flows. The ventilation route into the UILW vaults would be via the transfer tunnel and through the vault end wall below the crane maintenance area. This diversity will enable velocities to be controlled in the transfer tunnel during emplacement operations.

During disposal of UILW most of the ventilation would enter the vault via a shielded ventilation duct located at the end of the vault beneath the crane maintenance area. Once disposal is complete, and the shielded floor plug is replaced in the hatch, ventilation of the vault would be controlled completely by adjustable dampers within the shielded ventilation duct. The air would be drawn out of the far end of each vault via shielded ducting and through two sets of HEPA filters to remove any contaminated particles from the air. This would make the exhaust air suitable for discharge along the disposal area return roadways and, eventually, up exhaust shaft number 3.
The SILW/LLW vault ventilation filters would be located in a common filter room, and could be permanently on-line. The filter room would be sited close to the far end of the module of SILW/LLW vaults. The air would be drawn out of the far end of each vault, and along an active ventilation roadway to the filter room. It would then pass through two sets of HEPA filters, to remove any contaminated particles from the air and to make the exhaust air suitable for discharge to atmosphere. This air would enter the common disposal return roadways before being drawn through to shaft number 2 to the exhaust fans. The design of the ventilation system would allow progressive development of the disposal facility with concurrent construction and waste disposal. Isolation would be achieved by bulkheads between the two separate ventilation circuits, which could be moved to switch the ventilation of each newly commissioned vault to the waste emplacement area circuit.

9.3.2 Waste temperature – ILW/LLW waste temperature

Long-term increases in waste package temperature beyond the established long-term target of 50°C can impact on package corrosion and gas generation. The designs for operation would therefore be established to ensure, so far as possible by passive means, that the temperatures can be kept below this level. As a general principle, temperature would be minimised as far as is reasonably practicable. This includes the backfilling process, although short-term excursions above 50°C would be acceptable during this period, e.g. an operating temperature excursion of 80°C for up to 5 years [9].

9.3.3 Ventilation – HLW/SF disposal area

The disposal tunnels that would be used for the disposal of HLW, SF, plutonium and HEU would, initially, be single entry and ventilated using auxiliary methods. The use of an auxiliary ventilation system requires that a full ventilation circuit is maintained at all times within the relevant part of the facility. It should be noted that auxiliary ventilation will be required during construction and operation of the disposal tunnels. Once the disposal tunnel has been backfilled, there is no further need for ventilation. Bentonite swells and increases in volume with the addition of water. For the illustrative designs in a higher strength rock and lower strength sedimentary rock, the ventilation would be required to assist in controlling the relative humidity within the disposal tunnels, to minimise the impact of water on the bentonite blocks.

9.3.4 Waste temperature – HLW/SF waste temperature

A maximum target temperature is usually defined for HLW and SF engineered barrier systems (EBSs) to prevent excessive temperature from damaging the EBS materials. In particular, bentonite may lose key plasticity and swelling properties if subjected to high temperatures. Thermal convection (or water refluxing) resulting in mineral dissolution and re-precipitation can also degrade buffer performance, especially if it occurs before the buffer has re-saturated fully. For a higher strength rock, based on the KBS-3V concept and taking into consideration appropriate cooling periods, disposal hole spacings of 6.5m and disposal tunnels at 25m would enable temperatures at the buffer interface with the waste package to be maintained below a nominal 100°C [9]. Similarly, for a lower strength sedimentary rock, Nagra has adopted a tunnel spacing of approximately 40m, and a similar dimension would be used in this design.

At Gorleben, the host rock salt exhibits creep at high stresses without fracturing – a process that is accelerated at the high temperatures initially surrounding the waste packages (~150–200°C), which has been demonstrated in several in situ tests. This effectively seals the waste packages into impermeable rock, preventing any access of water from surrounding formations, as long as the salt dome remains stable. In the case of the design that is proposed, the backfill would comprise crushed rock salt, which, under pressure and assisted by heat generated by the waste, will help the backfill material...
become solid over time, with similar properties to the surrounding, undisturbed rock. It is assumed, for planning purposes, that the spacing between the disposal tunnels would be approximately 40m.

9.3.5 Rock drainage hall

The rock drainage hall would be situated close to the construction shafts, and would comprise pump and pipelines for water being fed to and removed from the sump. The water collected here would be water from the construction process and water entering the facility via the drift or shafts. Water would then be pumped up the drift or shaft number 1 to the water dispatch facility to undergo treatment, if required, before being pumped to a suitable licensed discharge point, or soakaway.

9.3.6 Disposal area drainage

The design of drainage systems for the underground areas would allow progressive development of the disposal facility with concurrent construction and waste emplacement. As the underground facility is developed the disposal areas (vaults and disposal tunnels) would progressively be transferred from the construction drainage circuit to the active effluent drainage circuit, by appropriate diversion and sealing. Liquid effluent from the active effluent drainage circuit, which would include all of the underground radiologically controlled areas (including the operational vaults and disposal tunnels), would be collected and brought up the surface by tanker for treatment in the active ventilation plant and liquid effluent treatment facility.

9.4 Electrical power supplies

A secure electrical power supply and distribution system would be essential for a GDF in order to maintain continuity of operational activities while ensuring plant and personnel safety and security.

In designing the electrical power and distribution system, it is be important to understand the functionality of the individual systems and work areas in order to determine the level of security of supply required. Each of the facility's systems would be examined to determine whether its electrical supply is considered ‘essential’ to the safety of a GDF and the workforce. Furthermore, in accordance with standard nuclear industry design practice, if an electrical device is required to allow the plant to be made safe or keep it in a safe condition, then it would be classed as ‘essential’. These essential supplies would include, for example, ventilation equipment, plant control systems, communication systems, fire detection and alarm systems, emergency lighting and security.

To achieve the required level of supply security and redundancy, the design principal implemented focuses on the duplication of both the electrical substation equipment and of the power cabling. This principle would be implemented throughout the site, from the distribution network operator (DNO) in-feed to the site through to the individual load points within a GDF, wherever possible. In this manner, each item classed as an essential load would be provided with two separate normal supplies, constituting a firm supply.

A normal supply is defined as a power supply derived from the DNO local network. The level of diversity that can be achieved for the in-feeds from the DNO would depend on the configuration of the electricity distribution system in the geographical area of the selected GDF location.

In addition to the duplication of equipment, the security of supply would be further supported by utilising duplication and separation of the power cabling. Wherever possible, each supply cable would follow a physically different route, so that an incident that results in the damage of one supply cable would be unlikely to affect the other supply. Where physical separation is not possible, then alternative methods such as fire barriers and cable protection systems would be utilised.
In the event of loss of normal supplies from the DNO, the power supply to the essential equipment would be maintained by means of a back-up power system. In accordance with the design principle, this would be achieved by way of a duplicate set of diesel generators, each suitably sized to maintain the essential load, and, where required, localised battery back-up uninterruptable power supplies.

The general basis of design is that a GDF would be considered as two distinct working areas, these being the waste emplacement and construction areas. In this way, the electrical power systems for each facility would be of a similar design and also allow cross-connection to further support the required supply reliability and availability.

Two independent firm supplies would be taken from the DNO network as the in-feeds to a GDF. These supplies would be derived from separate DNO circuits/feeders in order to maintain supply to a GDF in the event of loss of a single DNO supply. Each of these supplies would be capable on its own of providing all the electrical power required by the entire GDF.

These firm supplies would feed two surface substations, one substation located within the emplacement area and a second substation within the construction area. The surface substations would supply power to both their surface and underground facilities. The surface substation design would be based on duplication of in-feeds, transformers and distribution boards at each substation, with the capability to cross-connect substations in order to supply power to the entire GDF in the event of loss of supply at either surface substation. Additionally, each of the surface substations would include a dedicated diesel generator, suitably sized to maintain a GDF essential load in the event of total loss of the DNO supply. At the surface substations, the DNO in-feed voltage, typically 33kV, would be transformed down to 11kV for distribution to the surface facilities utilising a number of 11kV ring main unit (RMU) circuits and/or dedicated duplicate 11kV supplies, as deemed necessary, according to the load requirements. These 11kV site distribution supplies would feed suitably rated transformers and switchboards, situated at close proximity to their dedicated loads, providing step-down voltages to 6.6kV, 3.3kV and 0.4kV, as required by the facilities and specific plant items. The two surface substations would supply power to two underground substations, one in the emplacement area and the second in the construction area. Two independent and physically separated 11kV cables from the surface substations would feed each of the underground substations. These cables would be routed via the drift and shaft number 3 for the waste emplacement activities and via shaft numbers 1 and 2 for the construction activities.

The underground substations would primarily consist of duplicate distribution boards feeding 11kV RMU circuits, which in turn feed suitably rated transformers to step down voltages to 3.3kV and 0.4kV, as required. The underground substations would also have the capability to cross-connect in the event of loss of supply from one of the surface substations. Other local underground substations consisting of transformers and motor control centres would be established for major load items, such as pumping and ventilation/dehumidification plants, in addition to those for disposal and construction activities.

A separate substation would be established approximately halfway along the drift tunnel. This would consist of 11kV/0.4kV transformers and switchboards for general power associated with drift construction/maintenance activities and monorail general supplies, and a drift transport rectification substation providing redundant 1,500VDC locomotive traction supplies.

It is estimated that the total power demand for a GDF would be in the region of 20MVA at full operational load. The essential load, as supported by the diesel generators, is estimated to be in the region of 5.5MVA.

The design for the electrical supply and power distribution system would include meeting at least 20% of the facility’s total power demand from on-site renewable generation. This target could be met without compromising the security of supply to meet the essential load.
9.5 Fire safety systems

In order to prevent and reduce the risk of a fire, it would be necessary to ensure that the specifications for the buildings and equipment include, as appropriate, the requirements for fire-resistant or non-flammable materials to be used in their construction. Where this is not practicable, then the materials used would need to be assessed in terms of flammability, location of use, generation of noxious or toxic fumes in combustion, and the quantity and accumulation of these materials. This assessment would include consideration of the potential impact of the use of flammable liquids such as diesel fuel, oils used in hydraulic systems and lubricants.

The basic principles of the fire safety systems within a GDF would include:

- adoption of fire prevention measures in design, e.g. the use of flame-resistant materials, minimisation of combustibles, control of ignition sources, etc.
- provision of rapid fire detection, to provide early alert
- provision of effective fire-fighting capabilities
- minimisation of risk to workers and the general public
- provision of safe means of egress of personnel (and access for fire-fighters) by control of ventilation
- minimisation and control of the run-off of potentially contaminated water.

In addition, the design of the disposal facility would follow good practice in the mining industry with regard to fire prevention and provision of means for escape and rescue of personnel and the provision of a safe haven.

Specific fire safety measures within a GDF would include:

- Surface, fire and rescue station – serving both the surface and underground facilities, this would be a combination of a civilian fire station and a mines rescue station.
- Underground fire-fighting stations – two such facilities would be provided, one serving the construction area and the other the disposal area.
- Control of flammable materials – control would be exercised over the use and volume of flammable materials throughout the disposal facility, including careful segregation of flammable materials from waste-handling and transfers routes.
- Fire-fighting system – the fire water supply to a GDF would comprise duplicate, pressurised water mains with an emergency storage supply at the surface. Fire ranges would be sited in the ventilation intake roadways at suitable intervals and other locations of greatest fire risk.
- Portable or equipment-mounted fire extinguishers – these would be a combination of dry powder, carbon dioxide, foam or water sited at strategic locations, e.g. electrical substations and plant rooms.
- Fire-fighting and rescue plan – this would be prepared to show the position of all ranges, hydrants, valves, fire stations and fire points.

In an evaporite rock, it may be possible to use a water mist fire suppression system, which would introduce less water to the rock and reduce the risk of dissolution.

The ventilation system would play an important role in controlling the propagation of fires underground. It is also recognised that a fire may disrupt the normal ventilation flows. The ventilation system for construction and disposal areas would be segregated and provided by two discrete systems, and a fire affecting one system should not disrupt the other. In addition, the fitting of isolation and fire dampers to the air inlet side of the ventilation system at strategic locations, i.e. air intakes to the inlet cells, transfer tunnels and vaults, etc., which could be shut either automatically or manually would significantly reduce the oxygen being supplied to a fire in those areas.
9.6 Control systems

The control systems would provide control of systems and equipment performing operations throughout the disposal facility. They would allow local and remote control of equipment, monitoring of plant status, and acquisition of data from the various instrument systems, and would provide records of operational performance.

The long-term aim would be to enable virtually all the main disposal activities to be controlled and monitored from the central control room on the surface. However, more complex operations such as those within the inlet cells would be likely at times to require local operation, with direct operator viewing through windows to identify and rectify problems and help in maintenance work. Also, the operations would be controlled locally during commissioning and during initial operation until confidence in remote operation is gained. These system requirements would be reflected in the philosophy to provide the options to control underground operations from, local control stations, the underground control room or the surface central control room.

Beyond the clear need for remote handling of UILW packages and disposal canisters, other remote handling measures would be utilised. These would include remotely operated lifting beams to unload and load rail wagons and trailers, and the placement of the disposal canisters within the disposal tunnel, with the operator provided with a direct view of the operation assisted by close-up colour CCTV. Even so, there would be locations and activities for which local and manual control would remain appropriate, such as the handling of empty transport containers within the storage areas. Other operations such as contamination monitoring and decontamination of rail wagons and containers could only practically be done manually, with appropriate health physics supervision.

The control system would include a number of safety circuits. These must be independent of normal control circuits. As these safety circuits and also other elements of the control system would be classified 'essential' for the safety of the plant, the entire control system would be powered from a battery-backed electrical system.

The control system would interface with a number of other systems. One such system, the inventory tracking system, would pass information to and receive information from the control system, to ensure correct disposal records for every single waste package. The control system would also interface with other essential systems such as ventilation and fire detection, providing the necessary indication of status and alarms. The electronic control systems would be commensurate with established nuclear industry standards.

The fire detection, response and control systems for a GDF would be designed to incorporate with the general fire safety principles adapted from relevant good practice in both surface and underground environments.
10 Backfilling, sealing and closure

10.1 Context
Closure of the underground part of the disposal facility involves backfilling the disposal vaults and tunnels, sealing the underground openings and backfilling and closing the access ways. Most designs envisage this occurring in a stepwise manner with disposal tunnels/vaults being backfilled and sealed as soon as they are full, then emplacement panels would be sealed as they are filled and finally the entire disposal facility sealed when all waste has been emplaced. Such a process focuses on minimisation of potential degradation of both engineered barriers and the host rock due to the rock-mechanical, hydrogeological and geochemical perturbations caused by openings at depth, reduction of risks to operators associated with upkeep and monitoring of them and also reduction of environmental impacts of long-term drainage. However, early backfilling would cause potential conflicts with the desire to maintain ease of retrieval. Such trade-offs can only be sensibly assessed on a site-specific basis and hence are not considered in further detail here.

The decision on when to close the facility after all of the waste has been placed underground for final disposal will take into consideration the views of the local community. An assessment of the potential impacts of carrying out closure operations will be undertaken to optimise the process, taking account of the outcomes of discussions with the regulators and the local community. The exact condition of the surface site at the end of closure operations will be agreed through consultation with the UK Government, regulators and the local community.

10.2 Backfilling – ILW/LLW disposal vaults

Higher strength rock
Following emplacement of waste within a SILW/LLW or UILW disposal vault, it would be backfilled and sealed using Nirex reference vault backfill (NRVB), a cement-based material. Although there is only one backfill type to be used, there are two elements:

- local backfill, to fill the space around and in the immediate vicinity of the packages
- peripheral backfill, to fill the void between the waste stacks and walls and ends of the disposal vaults.

Peripheral backfill, manufactured using temporary facilities, would be placed during vault construction (e.g. a layer beneath the load-bearing floor). The dry backfill materials would be delivered to the surface site, as required, and temporarily held in silos on the surface. The separate materials would be transferred underground to a central batching and mixing area. This backfill batching area would be sited on the construction side of the disposal facility, and would comprise a series of silos for the storage of the dry backfill components. The components would be blended in this area and then transferred to the mixers within the backfill galleries.

Quality control would be exercised on the production of the backfill, and if any material were deemed unsuitable it would be discharged in the construction return roadway for recovery and removal. This could be carried out underground or, alternatively, the material could be recovered and dealt with at the surface.

Backfill galleries would be sited above the vaults, and one gallery would be used for backfilling two vaults (Figure 36). Backfill galleries would be 3m wide × 3m high and contain the mixers and boreholes connected to grout hoppers located in the disposal vault walls that would direct the grout to the appropriate locations within the waste stacks. This would be undertaken once all the waste has been emplaced.
It is assumed that a backfill ratio\(^8\) of approximately 1:1 is achieved. It is also assumed that the crown space above the waste is backfilled. Backfilling would take place in a single campaign after final waste emplacement using the backfill galleries.

**Figure 36  Backfill Galleries cross-section**

![Backfill Galleries cross-section](image)

**Lower strength sedimentary rock**

It is currently assumed that in the illustrative design in a lower strength sedimentary rock, the disposal vaults would be backfilled and sealed using cementitious grout, in two elements:

- local backfill, to fill the space around and in the immediate vicinity of the packages
- peripheral backfill, to fill the void between the waste stacks and walls and ends of the disposal vaults.

Peripheral backfill would be placed during vault construction (e.g. a layer beneath the load-bearing floor). A designated area would be required underground, for the wet mixing of the cementitious grout, from first waste disposal, as each SILW/LLW and UILW disposal vault would be backfilled on being filled. The dry backfill materials would be delivered to the surface site, as required, and temporarily held in silos on the surface. The separate materials would be pneumatically transferred down shaft number 1 to this central batching and mixing area. The backfill batching area would be sited on the construction side of the disposal facility, and would comprise a series of silos for the storage of the dry backfill components. The components would be blended in this area and then transferred to a mixing area located closer to the disposal vaults. A grout-mixing area would be available, servicing each module.

Quality control would be exercised on the production of the backfill, and if any material were deemed unsuitable it would be discharged in the construction return roadway for

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\(^8\) The backfill ratio is the volume of local backfill to the volume of conditioned waste.
recovery and removal. This could be carried out underground or, alternatively, the material could be recovered and dealt with at the surface.

It is assumed that a backfill ratio of approximately 1:1 is achieved. It is also assumed that the crown space above the waste is backfilled. It is assumed that backfilling would take place progressively as each vault is filled, using grout injected through pre-installed pipes suspended from the disposal vault roof and sidewalls.

**Evaporite rock**

In the illustrative design in evaporite rock, it is currently assumed that no backfilling would be required within the disposal vaults, as natural creep would close the excavations over time. In the case of thinner salt formations, however, crushed salt may be used to minimise the local perturbations resulting from such creep. However, chemical conditioning (buffering) of the waste packages is currently envisaged. This is undertaken by placing bags of magnesium oxide\(^9\) (MgO) on top of each column of waste packages. These would be placed on top of waste packages as each array is placed. The MgO buffer will be stored at the surface and transported underground via shaft number 1 in campaigns. An underground temporary store would be required to store the buffer prior to it being taken into the disposal vaults.

It is proposed that following emplacement of waste into a UILW disposal vault, the vault would be closed off with the shield doors.

### 10.3 Backfilling – HLW/SF disposal tunnels

#### Higher strength rock

When all the deposition holes in a disposal tunnel have been filled, the disposal tunnel would be backfilled with a mixture of crushed rock (70%) and bentonite (30%) \[^{23}\]. The backfill would also be used to infill unused or rejected deposition holes and the top 1.0m of each deposition hole (if this is not filled and capped immediately after emplacement.

**Lower strength sedimentary rock**

It is currently assumed that disposal tunnels would be progressively backfilled with pre-compacted bentonite pellets in the lower strength sedimentary rock illustrative design.

**Evaporite rock**

It is currently assumed that disposal tunnels would be progressively backfilled with crushed rock salt in the evaporite rock illustrative design.

### 10.4 Plugging and sealing strategy

#### Higher strength rock

Low-permeability seals consisting of highly compacted bentonite retained by a concrete structure would be constructed to isolate vault modules, disposal areas, shafts and the drift. Higher permeability material would be used as bulk infill between the low-permeability seals. This material would consist of crushed rock (if suitable – otherwise sand or gravel) in the ILW/LLW disposal area, and 70% crushed rock and 30% bentonite in the HLW/SF disposal area. To optimise the efficiency of sealing, the cross-sectional area of entrances/exits would be kept to the minimum practicable for construction, ventilation and operation.

Sufficient space would be provided to enable construction of each low-permeability seal, in host rock of low permeability. Seals would be constructed to a standard to maintain a permeability performance at least as low as the host rock in which the seal is constructed

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\(^9\) Magnesium oxide (MgO) absorbs moisture and CO\(_2\). It is a buffer against aqueous chemical conditions, and is an aid for controlling actinide solubility. Depending upon the organic content of the waste materials, an absence of buffer or a different buffer material may be used in practice,
and also minimise radionuclide contamination through the EDZ. Care would be taken in relation to the excavation of those areas where seals were planned, in order to optimise seal construction and performance.

**Lower strength sedimentary rock**

The disposal facility is expected to be constructed in a low-permeability environment. However, each HLW and SF disposal tunnel would be sealed at one end with highly compacted bentonite and a concrete bulkhead. A shield door would provide a seal at the tunnel entrance. A seal would be constructed across the end of the disposal tunnel reception area and the intervening area in-filled.

Seals would retain backfill materials within the disposal vaults and tunnels and also minimise the potential for radionuclide migration in the long term. To optimise efficiency of sealing, the location and tailoring of the seals would be undertaken including the cross-sectional area of entrances/exits would be kept to the minimum practicable for construction, ventilation and operation.

Each SILW/LLW disposal vault would be sealed at each end, and similar seals would be placed in the tunnels that provide access to each ILW/LLW disposal module. This type of seal would also be constructed at the exit end of a UILW vault. The seal at the UILW vault entrance would be provided by the existing shield door.

Additionally, low-permeability seals (a 40m length of highly compacted bentonite retained by a concrete structure) would be placed in the main disposal facility accesses (shafts and drift) at the facility horizon. Backfill material would then be placed to fill any void space. The final design of the sealing system would take account of the layout and geology, and the provision of additional seals would be considered where, for example, the access intersects a higher-permeability stratum. Seals would be constructed to a standard to maintain a permeability performance at least as low as the host rock in which the seal is constructed and also minimise radionuclide contamination through the EDZ. Care would be taken in relation to the excavation of those areas where seals were planned, in order to optimise seal construction and performance.

**Evaporite rock**

UILW and SILW/LLW vault access roads would be backfilled with crushed rock salt and then sealed off by construction of a rigid concrete wall. There would be a rigid concrete wall with contact grouting around the concrete component as required. The disposal tunnel reception area and access tunnels associated with the disposal of HLW, SF, plutonium and HEU would be in-filled with crushed rock salt, with periodic placement of tunnel seals. A tunnel seal is likely to comprise 0.5–1.0m of formwork, 15-30m apart, and in-filled with concrete.

To optimise the efficiency of sealing, the cross-sectional area of entrances and exits would be kept to a minimum practicable for construction, ventilation and operation. Seals are installed to isolate and prevent access to vaults, as there is no requirement to retain backfill material. They also minimise the potential for radionuclide migration for some long term scenarios (e.g. brine displacement by generated gas).

The shafts would be in-filled in one of two ways. One option, as proposed at the WIPP facility in the USA, is to construct a seal at the base of each shaft using salt-saturated concrete, with the monolith being sufficiently large enough to fill the shaft inset. The remainder of the fill would be various layers of compacted clay, crushed salt and asphalt water stops with concrete plugs above and below. The top 160m is compacted rock fill. A second option would be to in-fill the shafts using multi-component seals comprising salt concrete and bitumen, as at Gorleben in Germany. The final design of the sealing system would take account of the layout and geology, and additional seals may be provided.
10.5 Mass backfill
At the time of closure, the disposal vaults and tunnels would already have been sealed or
backfilled, and it would only be necessary to progressively backfill the remaining tunnels,
facilities (workshops, etc.), shafts and drift. A full breakdown of the backfill quantities is
given in Appendix F.

Higher strength rock
It is currently assumed that mass backfill would comprise crushed rock (70%) and
bentonite (30%) [23].

Lower strength sedimentary rock
It is currently assumed that mass backfill would comprise sand (70%) and bentonite (30%).

Evaporite rock
It is currently assumed that mass backfill would comprise crushed rock salt.

10.6 Closure strategy
The surface facilities would be decommissioned, stripped of engineering equipment and
demolished. The surface environment would be remediated and landscaped to the end
state agreed with the Government, regulators and the local community. Monitoring of the
closure operation and the environment would continue throughout the closure phase. For
planning purposes, a notional period of 10 years has been included, during which time
backfilling, sealing and closure will be implemented.

Monitoring of the closure operation and the environment would continue throughout the
closure phase (see Section 12). Records from a GDF would be placed in a national archive
for use as required by future generations. Any physical marking of the site that might be
required by the UK Government, regulators or in an agreement with the local community
would be undertaken.

Following closure, the facility would be the responsibility of the authority charged with
institutional control. A period of post-closure monitoring could be undertaken by that
authority.
11 Reversibility and ease of retrieval

11.1 Context
The term ‘retrievability’ is used to refer to a number of different approaches to remove radioactive waste from a GDF after it has been emplaced. NDA uses the following terms, as described by CoRWM [41] to distinguish between different types of retrieval activities:

Reversibility: is used internationally to denote the ability to reverse decisions, as part of a phased decision-making process. It has also been used in the UK to describe retrieval by reversing the original emplacement process (e.g. removal of emplaced waste packages using the vault emplacement crane, much as retrieval from an interim store). In this context, reversibility is only possible before any form of backfilling or sealing has taken place and is dependent on the continued integrity of the waste packages, disposal vaults and emplacement equipment.

Retrievability: is the term used where it is possible to withdraw the waste from a GDF by building in a methodology that would allow access to the waste even after vaults had been backfilled. This could be achieved, for example, by keeping access tunnels open for a period after emplacement and vault backfilling, and by ensuring that any buffer/backfill materials could be readily removed.

Recoverability: is a term developed by CoRWM to define situations when the waste is recovered from a closed GDF by mining or similar intrusive methods. Once access tunnels have been backfilled and/or a GDF has been sealed, intrusive re-excavation operations would be required to recover the waste. These would be likely to pose greater technical challenges and be more expensive than other forms of retrievability.

The degree to which wastes are ‘retrievable’, and the type of retrieval approach required, depends on a range of factors, including:

- the type of waste
- the disposal concept
- the time elapsed after emplacement
- the degree to which a GDF has been sealed
- the nature of the surrounding geological environment.

Future decision-making regarding retrievability will need to take account of relevant site-specific characteristics. The NDA recognises the Government’s view that a decision on whether or not to keep a GDF (or vaults within it) open once facility waste operations cease can be made at a later date. As the site assessment process progresses, decisions with respect to retrievability will be made in discussion with the independent regulators and local communities. The finalised design would then reflect the decisions made in the light of those discussions.

In the meantime, in line with Government policy as set out in the MRWS White Paper, RWMD will carry out its activities developing the UK geological disposal programme in such a way that the option for retrievability is not excluded. The policy and requirements of retrievability have already been discussed in detail in Section 1.6. This section considers how retrievability will be addressed in the different illustrative designs.

11.2 ILW and LLW
Preliminary support requirements would be identified during the site investigation, and developed as the disposal facility horizon is accessed and the actual rock mass characteristics become apparent, such as rock quality, strength, the spacing and number of joints, and groundwater. Strata movement in and around disposal vaults would be monitored as part of the development process, ensuring that appropriate support is
specified. If provision is to be made for possible retrieval of the waste packages at some point in the future, then it may be necessary to monitor the condition of the packages. This is discussed in more detail in Section 12.

Higher strength rock

For the illustrative design in a higher strength rock, the process of emplacement for ILW and LLW would be similar, in principle, to that applied to surface storage, allowing individual or batches of waste packages to be retrieved relatively easily. The design of stable vaults, if required, should allow ILW/LLW disposal vaults to remain open until all the waste has been emplaced, when a decision to backfill all vaults could be taken. The issue of reversibility from these vaults would therefore only require the re-opening of the vaults and re-use of the remote handling systems in the UILW vault and a stacker truck in the SILW/LLW disposal vaults. However, it is recognised that removal of packages using an overhead crane would be more selective than a stacker truck in the SILW vault, which would operate on a first-in last-out philosophy.

It has to be recognised that leaving filled vaults open introduces risks associated with unexpected mechanical failure of the rock, water inflow, build-up of explosive gasses and accelerated degradation of the waste packages. For such reasons, it may be decided to backfill vaults as soon as they are filled, however, once the vaults have been backfilled using Nirex Reference Vault Backfill (NRVB), the waste packages would be more difficult to retrieve, and a programme of re-excavation would be the only way to retrieve the waste packages. Various studies have been undertaken internationally to demonstrate retrievability of waste packages. In particular, Nirex has demonstrated the feasibility of using high-pressure water jets to retrieve ILW packages from disposal tunnels backfilled with NRVB [42].

As the backfilling and sealing programme progresses, it would become progressively more difficult to recover waste from the facility. After closure, this would require a programme of re-mining, which should be feasible with existing technology.

Lower strength sedimentary rock

The lower strength sedimentary rock illustrative design is currently based on a set of assumed parameters, but it is recognised that the approach to retrievability will be designed in more detail, when there is site-specific information on the host rock type.

The process of disposal for ILW and LLW would be similar in principle to that applied to surface storage, allowing individual or batches of waste packages to be retrieved relatively easily while the vault is still in operation. The issue of reversibility from these vaults would therefore only require the re-use of the remote handling systems in the UILW and a stacker truck in the SILW/LLW disposal vaults. Waste packages placed in the individual disposal vaults could only be retrieved sequentially. The last waste package to be emplaced would be the first waste package available for retrieval. Assumed underground rock support for the disposal facility is currently based on rock bolts and shotcrete, but the use of a concrete lining in some parts of the facility has not been discounted. These measures could allow disposal vaults and tunnels to remain open for longer periods, making it easier to retrieve waste packages.

The potential for cavern failure is likely to increase as the timescale over which the facility needs to remain open increases. Backfilling each disposal vault immediately following emplacement reduces this risk and provides physical protection for the waste packages. It also avoids the potential risks to workers associated with extensive monitoring and maintenance of the structures. Once the vaults have been backfilled, the waste packages would be more difficult to retrieve, and a programme of re-excavation would be required to retrieve them.

As the backfilling and sealing programme progresses, it would become progressively more difficult to retrieve waste from the facility. After closure, this would require a programme of re-mining, which should be feasible with existing technology.
**Evaporite rock**

For the illustrative design in an evaporite rock, the process of disposal for ILW and LLW would be similar in principle to that applied to surface storage, allowing individual or batches of waste packages to be retrieved while the vault is still operational. The issue of retrievability from these vaults would therefore only require the re-use of the stacker trucks. However, due to the creep characteristic exhibited by evaporites, over time, depending on the rate of creep, packages will be more difficult to retrieve, and a programme of re-excavation would be the only way to recover the waste packages.

As the backfilling and sealing of the access ways progresses, it would become progressively more difficult to recover the waste from the facility. After closure, this would require a programme of re-mining.

11.3 **HLW, SF, plutonium and HEU**

**Higher strength rock**

The overall programme for the illustrative design in higher strength rock assumes that each disposal tunnel would be backfilled as soon as all the deposition holes within it are filled with disposal canisters. Prior to backfilling, it is envisaged that retrieval of the disposal canisters would utilise the deposition machine and that the DCTC would accept the retrieved disposal canister. SKB (the Swedish Nuclear Fuel and Waste Management Company) has demonstrated that waste canisters can be retrieved from a saturated bentonite buffer by slurrying it with a saline solution [43].

However, should the decision be taken to recover the disposal canisters, once backfilling has taken place, then this would become a re-mining exercise – a more difficult, lengthy and costly process.

**Lower strength sedimentary rock**

The overall programme for the illustrative design in a lower strength sedimentary rock currently assumes that each disposal tunnel would be backfilled progressively as the disposal canisters are emplaced within it. It is technically feasible to remove the disposal canister from the pre-compacted bentonite pellets prior to sealing of the main access tunnels by reversing emplacement operations.

Should the requirement arise to recover the disposal canisters, once backfilling of the main access ways had taken place, then this would become a re-excavation process.

**Evaporite rock**

The overall programme for the illustrative design in evaporite rock assumes that each disposal tunnel is backfilled progressively as the disposal canisters are emplaced within it. Once backfilling has taken place, then, should the requirement arise to recover the disposal canisters, this would become a re-excavation process.
12 Monitoring

12.1 Context
Monitoring would be carried out at all stages of GDF development in order to provide assurance of the current and possible future safety performance, and to provide input to the technical and societal decision-making.

12.2 Baseline monitoring
Prior to the start of surface-based investigations, a baseline monitoring programme will be established to provide information for a long-term monitoring programme that will run throughout the remaining duration of the project. The monitoring of site baseline conditions (such as dust, noise, air quality, including radiological monitoring) would ensure that any impacts from our activities can be identified and mitigated.

12.3 Construction monitoring
During the construction phase of the development of a disposal facility a programme of monitoring would be managed to support the requirements of the safety case. These would include:
- Monitoring of non-radiological parameters to confirm understanding of the effects that construction, operation and closure of the facility have on the characteristics of the site.
- Monitoring of construction activities from the start of construction, and monitoring of ground movement to determine and confirm expected behaviour – to compare with expectations and develop geotechnical models to establish confidence in rock support designs.
- Monitoring to confirm that the site is being developed within the parameters set out in the environmental safety case specification and to ensure compliance with any discharge consents.
- Routine monitoring during construction such as groundwater inflow and the measurement of the geochemistry of the groundwater.

During construction, if monitoring indicates the development of local instability or that performance of the host rock is not as predicted, the design of the underground layout will be reviewed and modified accordingly.

12.4 Operational monitoring
During the operational period, protection of the public and the environment would be provided both through passive measures, i.e. measures that do not depend on human intervention or on any active engineered system, and through active measures that rely on people. The aim would be to provide monitoring as far as reasonably practicable through passive measures. The illustrative designs would include provision for:
- Package monitoring – records at dispatch, monitoring and checking on receipt, selective monitoring of waste packages to confirm package origin and content, performance and integrity.
- Planned preventative maintenance and routine condition monitoring of plant and equipment.

The monitoring requirements during the operational would also include the ongoing construction monitoring due to these activities running concurrently.
As progress is made towards closure of the facility, it is expected that engineered features conducive to long-term environmental safety would be completed progressively. A
progressive and planned shift from partial reliance on active measures and monitoring towards reliance on passive measures is anticipated.

If provision is to be made for possible retrieval of the waste packages at some point in the future, then it may be necessary to monitor the condition of the packages. A key technical issue here, therefore, is the need to better understand package longevity and the corresponding degradation mechanisms over a long period of storage. As part of the work underpinning the DSSC, further research into package longevity has been commissioned [44]. The aim of the work is to investigate whether it may be better to remove reliance on continuing package integrity by backfilling before degradation mechanisms have had time to adversely affect package performance.

It is recognised that facilities may need to be included in the future to inspect and potentially undertake repair or rework of waste packages, should monitoring and inspection indicate unacceptable deterioration.

12.5 Post-closure monitoring

The Environment Agency guidance document on requirements for authorisation (GRA) [7] advises that

"unreasonable reliance shall not be placed on human action to protect people and the environment and that assurance of environmental safety must not depend on monitoring or surveillance after the declared end of the period of authorisation."

However, there may be technical and social reasons to continue to monitor the facility during the post-closure period. Subsequent monitoring is not ruled out, provided it does not produce an unacceptable effect on the environmental safety case.
13 Security and safeguards

13.1 Context
As a GDF will be a civil licensed nuclear site, capable of disposing Category I to III nuclear material, a security plan must be approved by the OCNS under the authority of the Nuclear Industries Security Regulations 2003 [45].

13.2 Security
In accordance with the OCNS guidance document [46] which states how to prevent the disclosure of information that could assist a person or group planning theft or sabotage, this report does not contain information on the physical security arrangements assumed or planned in order for a GDF to protect nuclear and other radioactive materials and its related factors. This detail is contained within the GDF security plan. This will detail the security regime in place for the protection of a GDF, nuclear and other radioactive material and sensitive nuclear information on a GDF site. These arrangements would cover physical security protection features such as fencing, CCTV, access controls, intruder alarms and the roles of the security guard-force and the Civil Nuclear Constabulary.

It is assumed that a GDF should be designed and constructed to provide appropriate physical security features to operate as a Category I facility from the outset, but it will operate initially as a Category III facility from first receipt of ILW and LLW. This future-proofing will ensure sufficient surface area is available and minimise unnecessary disruption to GDF services and operations to prepare for subsequent future re-categorisation to Category I.

It is also assumed that prior to the receipt of HLW and SF, the GDF would be re-categorised to a Category II facility. In advance of plutonium and HEU disposal, it is assumed that a GDF will be re-categorised from a Category II to Category I civil licensed nuclear site. Each re-categorisation will involve increased control on access to all areas, and incorporate sufficient detection and surveillance systems to identify theft and sabotage attempts.

The waste emplacement area would be classified as a Designated Area, which includes the surface waste receipt and handling buildings. The full extent of this area is shown in Drawing E/DRG/0041000. All these facilities would be grouped near to the waste emplacement entrance (either drift or shaft), rail arrivals and dispatch sidings, to establish a single area.

Transport of nuclear material to and within a GDF site would have to be described in a transport security statement and an associated transport plan, also approved by OCNS.

13.3 Safeguards
The UK is a signatory of the Nuclear Non-Proliferation Treaty, and is committed to the nuclear non-proliferation regime to stop the spread of nuclear weapons. The verification of Treaty compliance is carried out by inspectors from the IAEA, under its safeguards agreements with member states [47]. Safeguards are technical and political measures which deter and ultimately detect the diversion of certain materials from peaceful civilian use to military use and thus the proliferation of nuclear weapons [47].

The emplacement of any nuclear material subject to safeguards in a GDF will require safeguards verification of the underground and surface facilities. This verification is to provide independent assurance that nuclear material is not being diverted from its declared disposal and that the system of nuclear material accountancy and control is acceptable. Achieving safeguards by design requires very early consultation with safeguards inspectorates of the European Commission and the IAEA. While this will be modelled on a
generic approach to safeguarding a GDF, it will later be tailored to a site-specific GDF design, host rock, and the type and form of nuclear materials emplaced. The design will have to incorporate sufficient safeguard measures to give assurance on the absence of diversion of nuclear materials. A measure of fundamental importance to safeguards is good nuclear material accountancy and control, and this may be independently verified by a variety of technical measures (e.g. containment and surveillance systems) and by tracking and monitoring material.

The level of safeguards provisions at a GDF would depend on the nuclear material emplaced, its accessibility, the complexity of design, the ability to track nuclear material through to emplacement and ease of retrievability. Safeguards will verify GDF construction activity against submitted designs and also verify emplacement of nuclear material during the operational phase.

As GDF design may initially allow for easy waste retrieval, safeguards inspection periods are expected to continue until sealing and closure. The measures to safeguard nuclear material can only be terminated if the nuclear material is practicably irretrievable [48] although this would conflict with any potential requirement for long-term retrieval.
14 Implications of additional wastes

14.1 Context

There are sources of uncertainty in the eventual inventory requiring geological disposal which are also covered by our work programme. These include uncertainties in the volumes and radionuclide contents of the currently identified wastes and materials in the Baseline Inventory and uncertainties in scenarios for the future operation of nuclear plants and other facilities that produce these wastes and materials. We must also consider the possible inclusion of SF, plutonium and uranium owned by the Ministry of Defence that are not currently within the Baseline Inventory.

We can create a range of scenarios for the inventory of wastes that may require geological disposal in order to evaluate the implications of these uncertainties for the geological disposal programme. In particular, we have developed an Upper Inventory, to give an indication of the quantities that might need disposal. We want to be able to demonstrate that a GDF can be developed to deal with this inventory safely and securely in addition to being confident that the same will be true for a lesser inventory. Due to uncertainties in the waste inventory, development of the illustrative designs must ensure that these are flexible to accommodate these and other potential materials.

The Baseline Inventory does not include radioactive waste arising from proposed new nuclear build in the UK. The volume of such waste produced would depend on factors such as the reactor type and the number of new reactors and their operational life. The UK Government considers that it would be technically possible, and desirable, to dispose of any waste arising from new nuclear build in a GDF alongside legacy waste, and has committed to exploring this through the MRWS process. The Upper Inventory is described in more detail in the DSTS [9].

The amounts of higher-activity wastes that new build may produce are not known. In order to deal with this uncertainty, a contribution of wastes from new build in the Upper Inventory has been included.

The Upper Inventory includes:

- LLW
- ILW (SILW and legacy and new-build UILW)
- HLW
- plutonium
- uranium (both HEU and DNLEU)
- Ministry of Defence used fuel
- new-build SF.

The Upper Inventory also provides visibility to local communities that are considering participation in the site selection process of what might be involved in hosting a GDF. This is so the implications of wastes from this source on geological disposal can be assessed. In particular, the relationship between the additional wastes and the implications for the size and design of a GDF and for the safety and environmental protection provided by the facility can be understood. These potential implications are discussed in the following subsections.

14.2 GDF surface facilities

The surface facilities for a GDF designed to manage the Upper Inventory are assumed to be the same as for the Baseline Inventory. The major implications for the design would be the impact on the underground footprint and operations. At present, it is assumed that the inventory and scheduling only require that a single underground access is available. If the
actual inventory is larger than currently envisaged and if the schedule of arrivals is more demanding than at present, then there may be a need for an additional underground access to accommodate the arrivals.

### 14.3 GDF underground facilities

The illustrative designs and layouts have been based on assumed parameters and typical host rock properties, and the site specific design would obviously depend on the characteristics of the chosen site such as the local stress field and fault zones.

**Higher strength rock**

The increase in radioactive waste associated with the Upper Inventory would require the number of UILW vaults to increase to 35, and the number of SILW/LLW disposal vaults increase to 13. A total of 549 disposal tunnels for HLW, SF, plutonium and HEU disposal would be required. This illustrative layout is shown in Figure 37.

**Figure 37 Illustrative underground layout for the Upper Inventory – higher strength rock**

The footprint for the Upper Inventory volume would increase to approximately 9.8km$^2$.

At the start of waste emplacement there would be two vaults to be ventilated from the drift, one UILW and one SILW/LLW, increasing to 35 UILW and 13 SILW/LLW disposal vaults at the end of the emplacement period, assuming the Upper Inventory scenario and that vaults are not backfilled immediately on completion of waste emplacement. The requirement to ventilate these vaults through to closure would place additional resistance on the ventilation system.

The resistance of the waste emplacement ventilation circuit would be increased by the flow regulation and protection dampers (protecting against back-flow from the vaults), with the need to balance flows from each of the 48 vaults and by the HEPA filters. To overcome the resistance and allow control of the flow, and balancing of this flow with the construction flow, booster fans may be provided downstream of the HEPA filters.

As the disposal facility underground layout increases in size, so would the volume of rock excavated. The majority of this material would need to be transported off site or stored in surface landscape bunds until reused underground as backfill.
Lower strength sedimentary rock

The increase in radioactive waste associated with the Upper Inventory would require the number of UILW vaults increase to 308, and the number of SILW/LLW disposal vaults increase to 161. There would be a requirement for 206 disposal tunnels for HLW, SF, plutonium and HEU disposal. This illustrative layout is shown in Figure 38.

Figure 38  Illustrative underground layout for the Upper Inventory – lower strength sedimentary rock

The footprint for the Upper Inventory volume would increase to approximately 19.5km$^2$. The impact of the Upper Inventory volume on ventilation requirements is likely to be small, as the same number of disposal vaults and tunnels would be in operation because vaults are sealed following disposal of waste, and disposal tunnels are not required to be ventilated once disposal ceases. In both cases, there is no need to provide ventilation through vaults and disposal tunnels to the closure phase.

As the disposal facility underground layout would increase in size, so would the volume of rock excavated. The majority of this material would need to be transported off site or stored in the surface landscape bunds until it was reused underground as backfill.

Evaporite rock

The increase in radioactive waste associated with the Upper Inventory would require the number of UILW vaults increase to 304, and the number of SILW/LLW increase to 78. For HLW, SF, plutonium and HEU disposal, a total of 206 disposal tunnels would be required. This illustrative layout is shown in Figure 39.
The footprint for the Upper Inventory volume would increase to approximately 18.4 km$^2$.

The impact of the Upper Inventory volume on ventilation requirements is likely to be small, as the same number of disposal vaults and tunnels would be in operation because vaults are sealed following disposal of waste, and disposal tunnels are not required to be ventilated once disposal ceases. In both cases, there is no need to provide ventilation through vaults and disposal tunnels to the closure phase.

As the disposal facility underground layout would increase in size, so would the volume of rock excavated. The majority of this material would need to be transported off site or stored until it was reused underground as backfill.

### 14.4 Operational programme

The total throughput for ILW for the Upper Inventory equates to some 226,000 packages. Between 2040 and 2123, prior to the arrival of DNLEU, the average throughput of the facility would be of the order of 2,100 packages per year. This number of packages can be accommodated within the capacity of a single inlet cell. However, if DNLEU were to arrive prior to 2123, then this throughput would exceed the maximum capacity of the inlet cell, and so a second inlet cell would be required. Inlet cells would therefore need to be operated in parallel to deal with this arrival rate, which would affect the construction requirements.

The disposal of current estimates of SF associated with new build would take an additional 31 years.
The drift capacity (or waste emplacement shaft capacity in the evaporite rock illustrative design) is about 3,900 packages per year, sufficient for transporting the increased number of waste packages of the Upper Inventory. However, there would be other transports required in the drift for personnel, large construction elements, etc., that would take up some of the capacity. Similarly, the arrival timing of such additional wastes may have implications for the design and operation of a GDF, particularly if they arrive over a relatively short period of time, and so an additional drift may be required. An alternative to this would be to consider more extensive utilisation of the shaft transfer capacity.

Due to the increase in the number of waste packages, a longer operational timescale is anticipated. This would create a need for extended maintenance of the underground access tunnels and shafts. The current illustrative designs assume that it will take 10 years for a disposal facility to be closed following final waste emplacement. With the increased footprint due to the additional wastes disposed, this closure period might increase assuming that this was not done in a stepwise (module by module) manner. There would, in any case, be an increase in the total quantity of buffer and backfill materials required.
15 Other design considerations

15.1 Context

At the current stage of the programme, we are examining a wide range of potentially suitable disposal concepts so that a well-informed assessment of options can be carried out at appropriate decision points in the implementation programme. Drawing from this work, we have set out illustrative designs for each of the three generic geological environments.

We are using these illustrative designs to:

- further develop our understanding of the functional and technical requirements of the disposal system
- further develop our understanding of the design requirements
- support the scoping and assessment of the safety, environmental, social and economic impacts of a GDF
- support development of our R&D programme
- underpin our analysis of the potential cost of geological disposal
- support assessment of the disposability of waste packages proposed by waste producers.

We have set out these illustrative designs solely for these purposes. We do not intend that one of these illustrative designs is necessarily the one that we would use in the relevant geological setting, and, at this stage, no geological disposal concept has been ruled out. Depending on the location of the GDF, there could be a number of additional design considerations on the design, and some of these are discussed in the following subsections.

15.2 Separate surface sites

The surface facilities would be the most visible aspect of the disposal system, and minimising visual impact would be an important design consideration. For instance, in some locations it might be possible to situate some of these facilities below the ground surface.

If it was not possible to locate all required surface facilities on a single site, then the division into a waste receipt site and a construction site would be viable option which would not necessarily affect the underground layout. The main constraint would be the location of a disposal facility access points (drift / shafts) relative to the GDF footprint in order to make logistics practicable.

Even if the surface facilities were to be located at two or more sites, then, depending upon the site selection process, the facility would still operate in the same way as the design outlined in this report.

15.3 Depth

The depth at which a GDF would be located is envisaged to be between 200m and 1,000m, but the exact depth will depend on the site geology. For planning purposes, a minimum depth of 200m is specified, to provide a depth of cover greater than the likely maximum extent of surface change in the very long term while the wastes are still hazardous [1].

The maximum depth of 1,000m is considered appropriate at this time for construction, but in some situations it might be possible to construct at even greater depths. As the depth of a disposal facility increases, the range of options available for access, construction, operation and closure reduces. Ambient temperatures rise and construction and
operational requirements increase, subject to the rock mass characteristics. The depth of any potential host geological environment will, therefore, be important in determining how the facility will be constructed, the excavation sizes, the support requirements and long-term stability in the underground environment and also decrease the risk of human intrusion activities.

15.4 Drift-only access

Drift-only access addresses the changes in layout from such an option which might be considered for a GDF at a relatively shallow depth (of about 300m) below ground level in low-permeability higher strength geological environments. Drift-only access could also be required if a GDF was to be located off-shore and accessed from land or if access directly above the underground facility was not possible.

The surface site would, however, need to be modified to reflect the change in access. Apart from minor changes at the base of the drifts, the underground layout and vault dimensions would not need to change.

Ventilation would be similar to the illustrative designs in this report, with the drifts acting as the emplacement intake, the construction intake, the emplacement return and the construction return, ensuring the segregation of systems.

15.5 Multi-level facility

The dimensions of the underground areas of a GDF would be determined by the inventory for disposal, the selected disposal concepts (the size of excavations and separation distances between emplacement zones), characteristics of the host geological setting (stress field, the presence of major structural discontinuities) and the near-field geology. Indicative underground layouts have been prepared for two inventory scenarios (Baseline and Upper Inventory). These simplified indicative layouts assume that the host geology is sufficiently extensive, vertically and horizontally, to accommodate it. Land ownership, planning boundary issues and the lateral extent of the host rock and the presence of layout-determining structures such as fault zones could limit the area available.

In practice, it may be possible or desirable to build a GDF over a smaller area, either by virtue of the host rock being sufficiently thick or due to the presence of a different, suitable host rock above or below the proposed facility horizon. If such geological conditions prevailed and if the rock mass characteristics were acceptable, then it could be possible to develop the facility on multiple levels.

If a multi-level facility was constructed, there would be little or no impact on the surface facilities or the underground workings, other than to reduce the horizontal extent of the underground. Where disposal vaults and tunnels are constructed on multiple levels, it is essential to ensure that sufficient separation is maintained to ensure that there is little or no significant detrimental interaction between them.
16 The way forward

It is stressed that while these illustrative designs have been developed for three generic geological environments (a higher strength rock, a lower strength sedimentary rock and an evaporite rock), it does not mean that these settings are in any way preferred, that any of the illustrative designs would necessarily be adopted for a selected site, or that any of the concepts are favoured more than any other.

This approach has been adopted to provide a number of illustrative designs which can be used in the associated assessments of safety, environmental, social and economic impacts and assessments of the costs to develop the facility.

Our proposed approach to evaluating geological disposal concept options and facility design solutions can be found in [49].

As the MRWS process progresses, details of a geological environment, site-specific characteristics and the disposal system design will become available. Until such time as more specific information becomes available, the approach that the NDA will continue to take is to define a limited number of generic geological disposal concepts applied to typical, potentially suitable UK geological settings. The DSS documents will initially describe generic requirements, reflecting the fact that a site and a disposal concept have yet to be identified. They will be periodically updated throughout implementation of a GDF, for example to respond to changes in regulations and to respond to learning from undertaking assessments. The DSTS, in particular, will evolve from generic to site-specific requirements as site-specific information becomes available at the more detailed level and as issues that are recognised today are resolved. Some issues are of a general nature and faced by other countries in implementing geological disposal, and some are UK-specific.

In order to plan the financing of the geological disposal programme and to inform the UK Government’s staged decision-making process, it has also been necessary to evaluate the potential cost of the geological disposal programme. This cost is affected by many factors, but the most significant are the inventory of waste, the timing of waste arisings, the timing and duration of each phase of implementation, the geology at the site of a GDF and the design of a GDF itself. More information about the cost of geological disposal can be found in Section 11 of ‘Geological Disposal: Steps Towards Implementation’ [2].
Glossary

**Advanced Gas Cooled Reactor (AGR)**
The reactor type used in the UK’s second-generation nuclear power plants.

**Backfill**
Three types of backfill are recognised:
- local backfill, which is emplaced to fill the free space between and around waste packages
- peripheral backfill, which is emplaced in disposal vaults between waste and local backfill, and the near-field rock or access ways
- mass backfill, which is the bulk material used to backfill the excavated volume apart from the disposal vaults or tunnels.

**Backfilling**
The refilling of the excavated portions of a disposal facility after emplacement of the waste.

**Baseline Inventory**
An estimate of the higher-activity radioactive waste and other materials that could, possibly, come to be regarded as wastes that might need to be managed in the future through geological disposal drawn from the UK Radioactive Waste Inventory.

**Buffer**
An engineered barrier that protects the waste package and limits the migration of radionuclides following waste package failure.

**Closure**
Technical and administrative actions to put a disposal facility in its intended final state after the completion of waste emplacement.

**Committee on Radioactive Waste Management (CoRWM)**
An organisation set up in 2003 to provide independent advice to the UK Government on the long-term management of the UK’s solid higher-activity radioactive waste. In October 2007, CoRWM was reconstituted with revised terms of reference and new membership. The committee will provide independent scrutiny and advice to the UK Government and devolved administration ministers on the long-term radioactive waste management programme, including storage and disposal. Further information available at www.corwm.org.uk.

**Conditioning**
Treatment of a radioactive waste material to create, or assist in the creation of, a wasteform that has passive safety.

**Conditioned waste volume**
The volume of the wasteform (waste plus immobilising medium) within the container.

**Consignor (of waste)**
An organisation or person that sends waste to a facility for disposal.

**Cover grouting**
Cover grouting is a method of injecting cementitious or chemical grouts into a rock mass for groundwater control in tunnelling and shaft sinking.

**Cut and cover**
A simple method of construction for shallow tunnels, where a trench is excavated and roofed over with an overhead support system strong enough to carry the load of the replaced material above the tunnel.
Disposal
In the context of solid waste, the emplacement of waste in a suitable facility without intent to retrieve it at a later date. Retrieval may be possible but, if intended, the appropriate term is ‘storage’.

Disposal facility (for solid radioactive waste)
An engineered facility for the disposal of solid radioactive wastes.

Disposal unit
A waste package, or a group of waste packages, which is handled as a single unit for the purposes of transport and/or disposal.

Emplacement (of waste in a disposal facility)
The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.

Environment Agency
The environmental regulator for England and Wales. The agency’s role is the enforcement of specified laws and Regulations aimed at protecting the environment, in the context of sustainable development, predominantly by authorising and controlling radioactive discharges and waste disposal to air, water (surface water, groundwater) and land. The Environment Agency also regulates nuclear sites under the Environmental Permitting Regulations and issues consents for non-radioactive discharges.

Environmental impact assessment (EIA)
A legal requirement under EU Directive 85/337/EEC (as amended) for certain types of project, including various categories of radioactive waste management project. An EIA requires information on the environmental impacts of a project proposal to be submitted by the developer and evaluated by the relevant competent authority (the planning authority, Health and Safety Executive or other regulators concerned).

Geological disposal
A long-term management option involving the emplacement of radioactive waste in a geological disposal facility, where there is no intention to retrieve the waste once the facility is closed.

High-level waste (HLW)
Radioactive wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities.

Indurated clay
Induration refers to the geological process whereby loose, water-bearing sediments are compressed by overlying younger sediments. Indurated clay rocks are defined as having a dry density greater than about 1.9t/m$^3$ and a uniaxial compressive strength of greater than 3.6MPa.

Inlet cell
A facility where unshielded intermediate-level waste is removed from its transport container under remote conditions before the waste is taken to the operational disposal vault.

Intermediate-level waste (ILW)
Radioactive wastes exceeding the upper activity boundaries for low-level waste but which do not need heat to be taken into account in the design of storage or disposal facilities.

Letter of Compliance (LoC)
A document, prepared by RWMD, that indicates to a waste packager that a proposed waste package is compliant with the relevant packaging criteria and disposal safety assessment, and is therefore deemed to be compatible with disposal in a GDF.
**Lifetime plan**
A plan that describes all the activities in terms of scope, schedule and cost to be undertaken on a nuclear site in the remaining period of its life-cycle to the end of final site close-out.

**Low-level waste (LLW)**
Radioactive waste having a radioactive content not exceeding 4 gigabecquerels per tonne (GBq/t) of alpha or 12GBq/t of beta/gamma activity.

**Managing Radioactive Waste Safely (MRWS)**
A phrase covering the whole process of public consultation, work by the Committee on Radioactive Waste Management (CoRWM), and subsequent actions by the UK Government, to identify and implement the option, or combination of options, for the long term management of the UK’s higher-activity radioactive waste.

**New build**
Any new nuclear power station.

**Nuclear Decommissioning Authority (NDA)**
The implementing organisation, responsible for planning and delivering a GDF. The NDA was set up on 1 April 2005, under the Energy Act 2004. It is a non-departmental public body with designated responsibility for managing the liabilities at specific sites. These sites are operated under contract by site licensee companies (initially British Nuclear Group Sellafield Limited, Magnox Electric Limited, Springfields Fuels Limited and the UK Atomic Energy Authority). The NDA has a statutory requirement under the Energy Act 2004 to publish and consult on its strategy and annual plans, which have to be agreed by the Secretary of State (currently the Secretary of State for Trade and Industry) and Scottish Ministers.

**Nuclear-licensed site**
Any site which is the subject of a license granted by the Nuclear installations Inspectorate (part of the Health and Safety Executive) under the Nuclear Installations Act 1965. Nuclear-licensed sites include nuclear power stations, nuclear fuel production and reprocessing sites, sites undertaking storage of and/or research into nuclear materials, and major plant producing radioisotopes.

**Office for Civil Nuclear Security (OCNS)**
The independent security regulator for the UK civil nuclear industry.

**Packaging**
The packaged waste volume is the displacement volume of a container used to package a wasteform.

**Plutonium (Pu)**
A radioactive element occurring in very small quantities in uranium ores but mainly produced artificially, including for use in nuclear fuel, by the neutron bombardment of uranium.

**Pressurised water reactor (PWR)**
A reactor type using ordinary water under high pressure as the coolant and neutron moderator. PWRs are widely used throughout the world for electricity generation. The Sizewell B reactor in Suffolk is of this design.

**Radioactive waste**
Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged.

**Radioactive Waste Management Directorate (RWMD)**
The NDA directorate established to design and build an effective delivery organisation to implement a safe, sustainable, publicly acceptable GDF programme. It is envisaged that
this directorate will become a wholly owned subsidiary company of the NDA. Ultimately, it will evolve under the NDA into the organisation responsible for the delivery of a GDF. Ownership of this organisation can then be opened up to competition, in due course, in line with other NDA sites.

Radioactivity
Atoms undergoing spontaneous random disintegration, usually accompanied by the emission of radiation

Rock mass
A large and indistinct body of rock containing features such as joints and folds.

Shielded waste package
A waste package that either has in-built shielding or contains low-activity materials, and thus may be handled by conventional techniques. In most cases, shielded waste packages are also designed to qualify as transport packages in their own right.

Shielding
The protective use of materials to reduce the dose rate outside of the shielding material. The amount of shielding required to ensure that the dose rate is as low as reasonably practicable will therefore depend on the type of radiation, the activity of the source, and on the dose rate that is acceptable outside the shielding material.

Spent fuel (spent nuclear fuel) (SF)
Used fuel assemblies removed from a nuclear power plant reactor after several years and treated either as radioactive waste or via reprocessing as a source of further fuel.

Strategic environmental assessment (SEA)
In this document, SEA refers to the type of environmental assessment legally required by EC Directive 2001/42/EC in the preparation of certain plans and programmes. The authority responsible for the plan or programme must prepare an environmental report on its likely significant effects, consult the public on the report and the plan or programme proposals, take the findings into account, and provide information on the plan or programme as finally adopted.

Stillage
A metal frame designed to hold four 500 litre drum waste packages so that they can be handled, stacked and transported as a single disposal unit.

Sustainability appraisal (SA)
A form of assessment used in England, particularly in regional and local planning, covering the social, environmental and economic effects of proposed plans and appraising them in relation to the aims of sustainable development. SAs fully incorporate the requirements of the Strategic Environmental Assessment Directive (2001/42/EC) are mandatory for a range of regional and local planning documents under the Planning and Compulsory Purchase Act 2004.

Transport container
A reusable container into which waste packages are placed for transport, the whole then qualifying as a transport package under the Transport Regulations.

Transport Regulations
The IAEA Regulations for the Safe Transport of Radioactive Material and/or those regulations as transposed into an EU Directive, and in turn into Regulations that apply within the UK. The generic term ‘Transport Regulations’ can refer to any or all of these, since the essential wording is identical in all cases.

UK Radioactive Waste Inventory (UK RWI)
A compilation of data on UK radioactive waste holdings, produced about every 3 years. The latest version, for a holding date of 1 April 2007, was published in June 2008. It is produced by Defra and the NDA. The UK RWI is the latest public record of information on
the sources, quantities and properties of low-, intermediate- and high-level waste in the UK. It comprises a number of reports and additional detailed information on the quantities and properties of radioactive wastes in the UK that existed at 1 April 2007 and those that were projected to arise after that date.

**Unshielded waste package**

A waste package that, owing to either radiation levels or containment requirements, requires remote handling and must be transported in a reusable transport container (the container and contents then forming a Type B transport package).

**Uranium (U)**

A heavy, naturally occurring and weakly radioactive element, commercially extracted from uranium ores. It is used as a fuel in nuclear reactors to generate heat by nuclear fission (the nucleus splitting into two or more nuclei and releasing energy).

**Vaults**

A tunnel that has been excavated and fitted out for the purpose of waste package emplacement.

**Waste container**

The vessel into which the wasteform is placed during manufacture of the waste package.

**Wasteform**

The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (i.e. in-drum mixing devices, dewatering tubes, etc.) but not including the waste container itself or any added inactive capping material. (NB. The single word ‘wasteform’ should not be confused with ‘waste form’ (i.e. two words), which usually refers to the physical and chemical form of an unconditioned waste).

**Waste package**

The complete assembly of waste container and wasteform as prepared in accordance with requirements for handling, transport, storage and disposal.
### Appendix A  Waste volumes for disposal

<table>
<thead>
<tr>
<th>Waste type</th>
<th>Volume of packaged waste (m$^3$)</th>
<th>Conditioned waste volume (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Upper Inventory</td>
</tr>
<tr>
<td>ILW</td>
<td>361,692</td>
<td>559,083</td>
</tr>
<tr>
<td>LLW</td>
<td>16,632</td>
<td>155,843</td>
</tr>
<tr>
<td>HLW</td>
<td>7,457</td>
<td>23,026</td>
</tr>
<tr>
<td>SF</td>
<td>10,363</td>
<td>2,097</td>
</tr>
<tr>
<td>Pu</td>
<td>6,989</td>
<td>10,401</td>
</tr>
<tr>
<td>U</td>
<td>94,502</td>
<td>118,730</td>
</tr>
<tr>
<td>New build</td>
<td>24,896</td>
<td>20,574</td>
</tr>
<tr>
<td>– ILW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New build</td>
<td>56,372</td>
<td>46,456</td>
</tr>
<tr>
<td>– U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New build</td>
<td>20,228</td>
<td>5,365</td>
</tr>
<tr>
<td>– SF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B  Waste package numbers

This section describes the various waste package types, their dimensions and the number of packages for each waste type that have been derived from the various inventories. There is also information on the characteristics of each of the package types.

**ILW and LLW waste packages**

<table>
<thead>
<tr>
<th>Waste package type</th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UILW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal stillages of 500 litre drums</td>
<td>33,079</td>
<td>43,941</td>
</tr>
<tr>
<td>Disposal stillages of 500 litre enhanced drums (precast)</td>
<td>570</td>
<td>736</td>
</tr>
<tr>
<td>Disposal stillages of 500 litre enhanced drums (basket)</td>
<td>5,731</td>
<td>8,160</td>
</tr>
<tr>
<td>Disposal stillages of 500 litre LLW drums</td>
<td>69</td>
<td>89</td>
</tr>
<tr>
<td><strong>Total Disposal stillages of 4 drums</strong></td>
<td><strong>39,449</strong></td>
<td><strong>52,926</strong></td>
</tr>
<tr>
<td>3 cubic metre drums</td>
<td>3,088</td>
<td>4,474</td>
</tr>
<tr>
<td>3 cubic metre box (round corners)</td>
<td>14,923</td>
<td>20,965</td>
</tr>
<tr>
<td>3 cubic metre box (square corners)</td>
<td>13572</td>
<td>39,725</td>
</tr>
<tr>
<td>Sellafield 3 cubic metre box (single skinned)</td>
<td>118</td>
<td>154</td>
</tr>
<tr>
<td>Sellafield 3 cubic metre box (double skinned)</td>
<td>10,802</td>
<td>14,042</td>
</tr>
<tr>
<td>3 cubic metre (round corners) LLW</td>
<td>0</td>
<td>7,401</td>
</tr>
<tr>
<td>Beta/gamma boxes</td>
<td>1,705</td>
<td>2,217</td>
</tr>
<tr>
<td><strong>SILW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAGR boxes</td>
<td>221</td>
<td>261</td>
</tr>
<tr>
<td>4 metre boxes (no shielding)</td>
<td>2,180</td>
<td>2,825</td>
</tr>
<tr>
<td>4 metre boxes (100mm concrete shielding)</td>
<td>1,071</td>
<td>1,392</td>
</tr>
</tbody>
</table>

---

10 A UILW disposal unit consists of either one 3 cubic metre box, one 3 cubic metre drum or four 500 litre drums contained in a stillage.
<table>
<thead>
<tr>
<th>Waste package type</th>
<th>Total number of disposal units$^{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline Inventory</td>
</tr>
<tr>
<td>4 metre boxes (200mm concrete shielding)</td>
<td>2,570</td>
</tr>
<tr>
<td>2 metre boxes (no shielding)</td>
<td>155</td>
</tr>
<tr>
<td>2 metre boxes (100mm concrete shielding)</td>
<td>85</td>
</tr>
<tr>
<td>2 metre boxes (200mm concrete shielding)</td>
<td>28</td>
</tr>
<tr>
<td><strong>LLW</strong></td>
<td></td>
</tr>
<tr>
<td>2 metre boxes</td>
<td>0</td>
</tr>
<tr>
<td>4 metre boxes (no shielding)</td>
<td>823</td>
</tr>
</tbody>
</table>

### HLW and SF package types and numbers

<table>
<thead>
<tr>
<th>Waste type</th>
<th>Total number of disposal Canisters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>HLW</td>
<td>3,656</td>
</tr>
<tr>
<td>AGR SF</td>
<td>5,341</td>
</tr>
<tr>
<td>PWR SF</td>
<td>655</td>
</tr>
<tr>
<td>MBGWS</td>
<td>n/a</td>
</tr>
<tr>
<td>PFR</td>
<td>n/a</td>
</tr>
<tr>
<td>Submarine</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>9,652</td>
</tr>
</tbody>
</table>

### Number of plutonium and uranium disposal units

<table>
<thead>
<tr>
<th>Waste type</th>
<th>Waste package type</th>
<th>Total number of disposal units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>Plutonium</td>
<td>Disposal canister (similar to HLW/SF)</td>
<td>3,426</td>
</tr>
<tr>
<td>HEU</td>
<td>Disposal canister (similar to HLW/SF)</td>
<td>50</td>
</tr>
<tr>
<td>DNLEU</td>
<td>Disposal stillages of 500 litre drums</td>
<td>41,332</td>
</tr>
</tbody>
</table>

$^{11}$ The Upper Inventory assumes that all AGR and PWR SF is reprocessed
Number of disposal units for the new-build reactor wastes [12]

<table>
<thead>
<tr>
<th>Waste type</th>
<th>Container type</th>
<th>Total number of disposal units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper Inventory</td>
</tr>
<tr>
<td>ILW</td>
<td>3 cubic metre box (round corners)</td>
<td>6,153</td>
</tr>
<tr>
<td>ILW</td>
<td>Disposal stillages of 500 litre drums</td>
<td>2,084</td>
</tr>
<tr>
<td>SF</td>
<td>Disposal Canister (new-build SF)</td>
<td>6,112</td>
</tr>
<tr>
<td>DNLEU</td>
<td>Disposal stillages of 500 litre drums</td>
<td>24,682</td>
</tr>
</tbody>
</table>

Total number of disposal canisters

<table>
<thead>
<tr>
<th>Inventory</th>
<th>Total number of disposal canisters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>13,126</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>24,323</td>
</tr>
</tbody>
</table>
## Appendix C  Summary of the illustrative designs

This table contains a high level summary of the illustrative design. Further information can be found in Section 7, 8 and 11.

<table>
<thead>
<tr>
<th>Geological environment</th>
<th>Higher strength</th>
<th>Lower strength sedimentary</th>
<th>Evaporite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface facilities</td>
<td>Bentonite buffer store</td>
<td>Bentonite buffer store</td>
<td>No bentonite used</td>
</tr>
<tr>
<td></td>
<td>Store for crushed rock and imported sand/cement</td>
<td>Store for imported sand/cement</td>
<td>Store for crushed salt and imported sand/cement</td>
</tr>
<tr>
<td>Underground access</td>
<td>3 shafts and 1 drift</td>
<td>3 shaft and 1 drift</td>
<td>4 shafts</td>
</tr>
<tr>
<td>Assumed depth for facility horizon (based on selected concept)</td>
<td>650m depth</td>
<td>500m depth</td>
<td>650m depth</td>
</tr>
<tr>
<td>Waste package transport</td>
<td>Via drift</td>
<td>Via drift</td>
<td>Via shaft</td>
</tr>
<tr>
<td>Underground rock support</td>
<td>Rock bolts and mesh with shotcrete</td>
<td>Rock bolts and mesh with shotcrete. Concrete segments not discounted</td>
<td>Rock bolts and mesh</td>
</tr>
<tr>
<td>Inlet cell requirements</td>
<td>1 inlet cell required</td>
<td>More than 1 inlet cell required</td>
<td>More than 1 inlet cell required</td>
</tr>
<tr>
<td>SILW/LLW disposal vault dimensions</td>
<td>Arch roof profile 16m × 15m and 300m long</td>
<td>Horse shoe shape 9.6m × 11.5m and 100m long</td>
<td>Rectangular shape 10m × 5.5m and both 90m or 225m long</td>
</tr>
<tr>
<td>UILW disposal vault dimensions</td>
<td>Arch roof profile 16m × 16m and 300m long</td>
<td>Horse shoe shape 9.6m × 11.5m and 100m long</td>
<td>Rectangular shape 10m × 5m and 100m long</td>
</tr>
<tr>
<td>HLW and SF disposal tunnel dimensions</td>
<td>Arch roof profile 5.5m × 5.5m and 340m long</td>
<td>Circular shape 2.5m diameter and 800m long</td>
<td>Rectangular shape 4.5m × 3.5m and 800m long</td>
</tr>
<tr>
<td>Disposal of SILW/LLW</td>
<td>Manually operated stacker truck</td>
<td>Manually operated stacker truck</td>
<td>Manually operated stacker truck</td>
</tr>
<tr>
<td>Disposal of UILW waste</td>
<td>Remotely using an overhead crane</td>
<td>Remotely using an overhead crane</td>
<td>Remotely using a rail mounted stacker truck</td>
</tr>
<tr>
<td>Disposal of HLW, SF, plutonium and uranium</td>
<td>Vertical boreholes surrounded with bentonite rings</td>
<td>Horizontally in disposal tunnels on pre-stacked bentonite blocks and surrounded with bentonite pellets</td>
<td>Horizontally in disposal tunnels on a sacrificial stool and surrounded with crushed rock salt</td>
</tr>
<tr>
<td>Underground transport of HLW, SF, plutonium and uranium</td>
<td>By locomotive to the transfer hall and then transported to the disposal tunnel in a free steered vehicle</td>
<td>By locomotive to the transfer hall and then transported to the disposal tunnel reception area by locomotive</td>
<td>By locomotive to the transfer hall and then transported to the disposal tunnel reception area by locomotive</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Idealised surface footprint</td>
<td>Approximately 1km²</td>
<td>Approximately 1km²</td>
<td>Approximately 1km²</td>
</tr>
<tr>
<td>Underground footprint – Baseline Inventory</td>
<td>Approximately 5.6km²</td>
<td>Approximately 10.3km²</td>
<td>Approximately 8.8km²</td>
</tr>
<tr>
<td>Indicative underground dimensions – Baseline Inventory</td>
<td>5,000m long × 2,000m wide</td>
<td>5,000m long × 4,000m wide</td>
<td>5,500m long × 4,000m wide</td>
</tr>
<tr>
<td>Volume of excavated material – Baseline Inventory</td>
<td>Approximately 7,450,000m³</td>
<td>Approximately 6,050,000m³</td>
<td>Approximately 6,250,000m³</td>
</tr>
<tr>
<td>UILW disposal vaults numbers – Baseline Inventory</td>
<td>19</td>
<td>169</td>
<td>167</td>
</tr>
<tr>
<td>SILW/LLW disposal vaults numbers – Baseline Inventory</td>
<td>6</td>
<td>77</td>
<td>38</td>
</tr>
<tr>
<td>HLW, SF, Pu and U disposal tunnels numbers – Baseline Inventory</td>
<td>296</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Backfilling – UILW/SILW/LLW disposal vaults</td>
<td>NRVB injected into vaults prior to closure.</td>
<td>Cementitious grout injected into vault once each vault is filled</td>
<td>No backfill, sacks of MgO placed on top to absorb moisture and carbon dioxide</td>
</tr>
<tr>
<td>Backfilling – HLW, SF, Pu and U disposal tunnels</td>
<td>Backfilled once all boreholes in a disposal tunnel are filled. Backfill would be blocks of bentonite and crushed rock (30:70 ratio)</td>
<td>Backfilled progressively as the disposal canisters are placed. Backfill would be bentonite pellets</td>
<td>Backfilled progressively as the disposal canisters are placed. Backfill would be crushed rock salt</td>
</tr>
</tbody>
</table>
tunnels and underground facility areas.
Appendix D  Construction materials and volumes

Volumes of excavated materials

<table>
<thead>
<tr>
<th>Inventory scenario</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Inventory</td>
<td>7,450,000m$^3$</td>
<td>6,050,000m$^3$</td>
<td>6,250,000m$^3$</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>13,800,000m$^3$</td>
<td>11,750,000m$^3$</td>
<td>11,350,000m$^3$</td>
</tr>
</tbody>
</table>

Volume of construction materials

It is anticipated that the volume of concrete required to construct the underground facilities including the shafts and drift will be as follows:

<table>
<thead>
<tr>
<th>Inventory scenario</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Inventory</td>
<td>350,000m$^3$</td>
<td>705,000m$^3$</td>
<td>350,000m$^3$</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>595,000m$^3$</td>
<td>1,350,000m$^3$</td>
<td>600,000m$^3$</td>
</tr>
</tbody>
</table>

It is anticipated that the volume of shotcrete required to construct the underground facilities, including the shafts and drift, will be as follows:

<table>
<thead>
<tr>
<th>Inventory scenario</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Inventory</td>
<td>210,000m$^3$</td>
<td>885,000m$^3$</td>
<td>530m$^3$</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>390,000m$^3$</td>
<td>1,775,000m$^3$</td>
<td>530m$^3$</td>
</tr>
</tbody>
</table>

The volume of steel reinforcement associated with the seals is expected to be:

<table>
<thead>
<tr>
<th>Inventory scenario</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Inventory</td>
<td>2,000t</td>
<td>2,800t</td>
<td>2,800t</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>2,500t</td>
<td>4,400t</td>
<td>4,000t</td>
</tr>
</tbody>
</table>

---

12 It is assumed that shotcrete is unlikely to be used in the underground facility in evaporite host geology, but that the anticipated volume of shotcrete would be required for the shaft construction.
The coverage and number of rock bolts to support the underground openings is expected to be:

<table>
<thead>
<tr>
<th>Inventory scenario</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>Based on 20% coverage</td>
<td>Based on 40% coverage</td>
<td>Based on 50% coverage</td>
</tr>
<tr>
<td>Baseline Inventory</td>
<td>150,000</td>
<td>450,000</td>
<td>575,000</td>
</tr>
<tr>
<td>Upper Inventory</td>
<td>220,000</td>
<td>900,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>
### Appendix E  GDF footprint

The footprint for the higher strength rock illustrative design would consist of:

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW vaults</td>
<td>350,000m²</td>
<td>630,000m²</td>
</tr>
<tr>
<td>SILW/LLW vaults</td>
<td>90,000m²</td>
<td>230,000m²</td>
</tr>
<tr>
<td>HLW/SF disposal tunnels</td>
<td>2,250,000m²</td>
<td>4,150,000m²</td>
</tr>
<tr>
<td>Roadways and support area</td>
<td>2,900,000m²</td>
<td>4,800,000m²</td>
</tr>
<tr>
<td>Total footprint</td>
<td>5.6km²</td>
<td>9.8km²</td>
</tr>
</tbody>
</table>

The footprint for the lower strength sedimentary rock illustrative design would consist of:

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW vaults</td>
<td>590,000m²</td>
<td>1,100,000m²</td>
</tr>
<tr>
<td>SILW/LLW vaults</td>
<td>260,000m²</td>
<td>550,000m²</td>
</tr>
<tr>
<td>HLW/SF disposal tunnels</td>
<td>3,300,000m²</td>
<td>6,900,000m²</td>
</tr>
<tr>
<td>Roadways and support area</td>
<td>6,150,000m²</td>
<td>11,000,000m²</td>
</tr>
<tr>
<td>Total footprint</td>
<td>10.3km²</td>
<td>19.5km²</td>
</tr>
</tbody>
</table>

The footprint for the evaporite rock illustrative design would consist of:

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW vaults</td>
<td>600,000m²</td>
<td>1,100,000m²</td>
</tr>
<tr>
<td>SILW/LLW vaults</td>
<td>150,000m²</td>
<td>300,000m²</td>
</tr>
<tr>
<td>HLW/SF disposal tunnels</td>
<td>3,300,000m²</td>
<td>6,900,000m²</td>
</tr>
<tr>
<td>Roadways and support area</td>
<td>4,700,000m²</td>
<td>10,100,000m²</td>
</tr>
<tr>
<td>Total footprint</td>
<td>8.8km²</td>
<td>18.4km²</td>
</tr>
</tbody>
</table>
Appendix F  Backfill materials and volumes

For the higher strength rock illustrative design, the following buffer and backfill materials will be required:

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW and SILW/LLW – NRVB(1)</td>
<td>1,250,000m$^3$</td>
<td>2,300,000m$^3$</td>
</tr>
<tr>
<td>HLW/SF bentonite buffer</td>
<td>285,000m$^3$</td>
<td>650,000m$^3$</td>
</tr>
<tr>
<td>HLW/SF disposal tunnel backfill(2)</td>
<td>2,300,000m$^3$</td>
<td>4,300,000m$^3$</td>
</tr>
</tbody>
</table>

Notes:
1. All these quantities assume that the crown space of the SILW/LLW and UILW vaults would be filled during backfilling operations. A backfill ratio of 1:1 is assumed.
2. Comprising crushed rock and bentonite in a ratio of 70:30.

For the lower strength sedimentary rock illustrative design, the following buffer and backfill materials will be required:

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW and SILW/LLW – cementitious grout(1)</td>
<td>1,300,000m$^3$</td>
<td>2,500,000m$^3$</td>
</tr>
<tr>
<td>HLW/SF bentonite buffer blocks and backfill(2)</td>
<td>350,000m$^3$</td>
<td>725,000m$^3$</td>
</tr>
</tbody>
</table>

Notes:
1. All these quantities assume that the crown space of the SILW/LLW and UILW vaults would be filled during backfilling operations. A backfill ratio of 1:1 is assumed.
2. Bentonite is used as blocks for the disposal canister to rest on. The disposal tunnel backfill is assumed to be pre-compacted bentonite pellets.

For the evaporite rock illustrative design, the following buffer and backfill materials will be required.

<table>
<thead>
<tr>
<th></th>
<th>Baseline Inventory</th>
<th>Upper Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>UILW and SILW/LLW – MgO(1)</td>
<td>175,000m$^3$</td>
<td>350,000m$^3$</td>
</tr>
<tr>
<td>HLW/SF crushed rock salt in disposal tunnel backfill</td>
<td>1,200,000m$^3$</td>
<td>2,500,000m$^3$</td>
</tr>
</tbody>
</table>

Note:
1. Sacks of MgO would be placed on top of the waste stack. Due to the nature of the host rock, there would not be any requirement for local or peripheral backfill.
References


Drawings
Underground UILW Emplacement Support Facilities - Longitudinal Section 1-1

Underground UILW Emplacement Support Facilities - Longitudinal Section 2-2
Longitudinal Section Through SILW/LLW Vault – 2m and 4m Boxes
Longitudinal Section Through SILW/LLW Vault - 2m and 4m Boxes
Longitudinal Section Through UILW Vault - 4 x 500 Litre Drums in Compact Stillages
UILW Vault

SILW/LLW Vault
Longitudinal Section Through SILW/LLW Vault - 2m and 4m Boxes